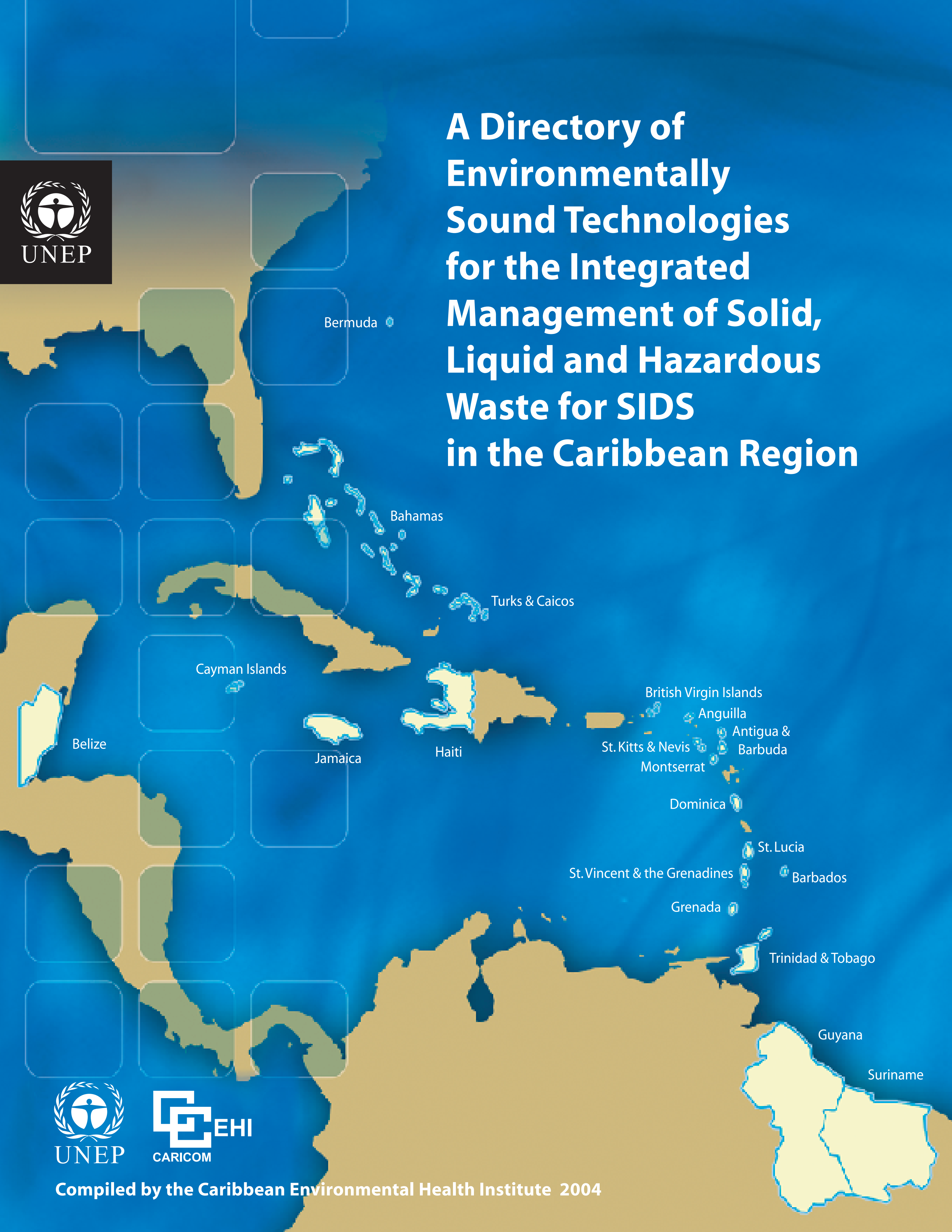
A Directory of Environmentally Sound Technologies for the Integrated Management of Solid, Liquid and Hazardous Waste for SIDS in the Caribbean Region



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CEHI CARICOM

Compiled by the Caribbean Environmental Health Institute 2004

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Compiled by the Caribbean Environmental Health Institute (CEHI)
March 2004

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DISCLAIMER

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PREFACE

As highlighted in the 1994 Barbados Programme of Action waste management is a major area of concern for small island developing States (SIDS). SIDS like other developing countries, have problems with the management of waste. However, SIDS experience additional constraints arising from small land area, high dependence on imports and high population densities exacerbated by high tourist inflows. Because of limited access to appropriate technologies, in many occasions, waste management technologies are transferred from larger and more developed countries, and as such are not always suitable for SIDS. Some SIDS have developed appropriate technologies, which have been successfully employed, but the information has not been shared with other SIDS in the same regions or in other regions. Hence the need for the Directory which compiles a list of practical technologies applicable to SIDS.

UNEP, in partnership with SIDS regional institutions, embarked on a programme to improve the access of SIDS to appropriate technology. A draft directory containing technologies found to be appropriate for SIDS from practical experience as well as literature review was compiled. It was subjected to peer review at a global level by experts from regional SIDS institutions (Caribbean, Indian, Mediterranean and Atlantic Ocean SIDS(IMA/SIDS) and Pacific), UN and other international agencies. The review was made at the UNEP Meeting of Experts on Waste Management in Small Island Developing States Waste Management in SIDS, held in London from 2 and 5 November 1999. The experts found the technologies to be appropriate to SIDS and recommended that each SIDS region further reviews and adapts the technologies according to their conditions.

The IMA/SIDS and Pacific regions have adapted the technologies to suit their conditions and published directories for their regions. This document 'A Directory of Environmentally Sound Technologies for the Integrated Management of Solid, Liquid, and Hazardous Waste for Small Island Developing States (SIDS) in the Caribbean Region' is the result of a review of the original directory by national experts from the Caribbean countries in Basseterre, St. Kitts, December 2003.

This publication is part of UNEP collaboration with SIDS on the implementation of the Waste Management chapter of the Barbados Programme of Action. Through this initiative a series of publication have been made. The Strategic Guidelines for Integrated Waste Management in SIDS were developed with inputs from all SIDS regions and reviewed by SIDS. The guidelines are based on the premise that, if systematic improvements are introduced at the various stages of the waste cycle, the quantity of waste to be managed at each of the subsequent stages would be reduced considerably.

The second document included in the UNEP waste management series is the IMA-SIDS Waste Management Strategy with special emphasis on Minimisation and Resource Recovery. These were developed with input from national experts in the region and adopted by the governments in the region.

It is hoped that these publications will make a useful contribution to the promotion of integrated waste management in SIDS in particular those in the Caribbean region, and will foster an increased awareness about the special circumstances of SIDS, especially the fact that these states face special constraints in their options for sustainable development.

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ABBREVIATIONS

BOD	Biochemical Oxygen Demand
CBO	Community Based Organisation
CEHI	Caribbean Environmental Health Institute
EST	Environmentally Sound Technology
EU	European Union
GCL	Geosynthetic Clay Liner
HAZMAT	Hazardous Material
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
NGO	Non Governmental Organisation
OECS	Organisation of Eastern Caribbean States
SWM	Solid Waste Management
SWME	Solid Waste Management Entities
SIDS	Small Island Developing States
UASB	Upflow Anaerobic Sludge Blanket
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

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UNEP and CEHI acknowledge the following institutions for their role in preparing the base document: South Pacific Regional Environment Programme, the South Pacific Applied Geoscience Commission, Indian Ocean Commission, Island and Small States Institute and the Organisation of Eastern Caribbean States.

UNEP and CEHI thank the Government of St. Kitts and Nevis and particularly the Ministry of Health and Environment for providing host country support for the Meeting at which the Directory was developed.

Finally, thanks to all the participants who included country representatives as well as private consultants who gave so generously of their time and expertise in order to complete the Directory.

1.0 INTRODUCTION

Solid waste management is an important aspect of the sustainable development agenda for the Caribbean region, primarily because of its social, economic and environmental implications, particularly on the tourism industry.

The sustainable management of wastes can contribute to economic growth, health and environment protection, poverty reduction and human welfare.

On the other hand most of the SIDS countries agreed to implement the Agenda 21 and the development goals, which include taking actions to protect human health and the environment.

There are numerous waste management technologies used throughout the world. Many of these technologies have been used in the Caribbean, but some have failed for a range of reasons. Reasons for failure include being an inappropriate technology, having insufficient operation and maintenance inputs and a lack of funding and/or skilled personnel. This Directory focuses primarily on proven sound environmental technologies for waste management plus those currently successfully being used in Small Island Developing States within the Caribbean Region. In addressing each broad waste management topic, sound practices are also provided, based on lessons learnt from the past. These sound practices give guidelines for selection of the most appropriate of the technologies listed for a given application. The sound practices can also be used to evaluate any existing or new technologies that arise in the future and which are not listed in this Directory.

Readers should note that the technologies presented in this Directory are also applicable to Small Island Developing States in other Regions as well as large continental lands.

In this Directory, sound waste management technologies have been grouped into categories of:
- Solid Waste
- Hazardous Waste
- Liquid Waste or Wastewater

1.1 Guiding Principles

This Directory was developed based on certain fundamental Guiding Principles. It is recommended that these principles be followed when choosing technologies and systems. They include:

1. Type and Efficiency of Technology
2. Use of Risk-Based Approaches
3. Stimulation of NGO, Community-Based Organisations (CBOs)/Private Sector Involvement
4. Regional Strategy
5. Economic Evaluation
6. In-house capacity
7. Potential for sustainability

2.0 SOLID WASTE TECHNOLOGIES

2.1 Introduction

Prior to the introduction of imported goods and packaging, the waste produced from a typical Caribbean country was almost entirely organic in origin and could be broken down or composted without thought or problem. To varying degrees, the majority of Caribbean countries have now moved from this lifestyle toward cash based, consumer goods societies. This shift can be attributed to global influences, tourism and imported goods.

As a result, waste products which do not break down easily and which are harmful to the environment have increased to the point where significant problems are being experienced. In the majority of cases, Caribbean islands have not been aware of the need, nor have they been able to develop suitable waste management systems to cope with these changes in waste character.

Environmentally Sound Technologies (ESTs) are therefore needed for the Caribbean Region to help solve the problems that now exist and to ensure that further environmental and health related problems do not occur as a result of solid wastes.

In 1996, the United Nations Environment Programme's (UNEP) International Environmental Technology Centre (IETC) published the "International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management" (Technical Publication Series No. 6). This book presented information about different Municipal Solid Waste Management (MSWM) technologies that are currently used in different regions of the World and gave a guide as to which of these are economically feasible and Environmentally Sound Technologies (ESTs).

The task of identifying ESTs is complicated by the fact that what constitutes an EST is highly dependant on the environmental, economic, climatic, cultural and social context in which the technology is set.

It is for this reason that the current Directory has been prepared, to identify and describe ESTs that are suited to the environmental, economic, climatic, cultural and social context of the Caribbean Region. As was done in the International Source Book, this Directory, focused on the Caribbean Region, is structured around 6 separate topics of solid waste management. These 6 topics relate directly to the physical materials and processes of waste management. The topics are:

a. Waste Reduction
b. Collection
c. Composting
d. Incineration
e. Landfills
f. Special wastes (These are covered in Section 3 Hazardous Wastes)

Other issues relating to overall waste management are waste characterisation, management and planning, training, public education and financing.

It needs to be stressed at this point that the use of particular technologies discussed in the following pages must be integrated into an overall waste management strategy in order to be effective.

2.1.1 What is a Sound Practice?

The question "What is a ***sound*** practice for waste management?" needs to be asked, before identifying Environmentally Sound Technologies (ESTs) for the Caribbean Region. In this regard, the UNEP International Source Book defines a "Sound Practice" as "a technically and politically feasible, cost effective, sustainable, environmentally beneficial and socially sensitive solution to an MSWM problem".

Extending this definition to the Caribbean Region, a sound practice not only achieves the management of solid waste, but also in the process, takes into account the specific physical, environmental, economic and political and social background conditions of the area. For the SIDS of the Caribbean, these background conditions (which tend to make solid waste management difficult) include:

- high population density on some small islands, accelerated by high growth rates,
- small population numbers spread over many small islands,
- high tourist numbers over a limited time,
- lack of funding from within SIDS governments,
- poor planning,
- limited land area to deal with waste absorption capacity,
- low levels of training and education,
- fragile environments

Alternative technologies and waste management strategies need to be evaluated to identify whether they fit in with the background conditions of the Caribbean and hence whether they are "sound".

This directory identifies a number of ESTs that have the potential for negative environmental impacts if not adopted properly. Determining an acceptable level of environmental impacts depends on the standards in use. Some SIDS have already developed or adopted environmental standards that govern air and water quality. However in the absence of any national standards, regional or international guidelines such as WHO, USEPA, or EU standards can be employed.

The following are criteria used by UNEP in their International Source Book for evaluating technologies and policy.

2.1.2 Criteria for Evaluating Alternatives

a) Is the option likely to accomplish its purpose in the circumstances where it would be used?

b) Is the option technically feasible and appropriate given the financial and human resources available?

c) Focusing on the financial aspects of the option, is it the most cost-effective option available?

d) What are the environmental benefits and costs of the option?
Could the environmental soundness of the option be significantly enhanced, given a small increase in cost? Conversely, would it be possible to significantly reduce the cost, with only a small detriment to the environment?

e) Is the practice administratively feasible and sensible?

f) Is it practical in the given social and cultural environment?

g) How would specific sectors of society be affected by the adoption of this option?

h) Does the application of a particular technological solution fit into the policy and legislative framework of the country, e.g. high-tech solutions versus low-tech labour intensive solutions? Can technology employed comply with environmental standards in force?

i) Will the risks associated with the choice of a particular approach support investment decisions?

j) Can the decision to use technology-based approaches to waste management support the creation of viable small and medium enterprises?

k) Does it reduce the threat to public health and the environment?

l) Do these effects promote or conflict with overall social goals of the country?

2.1.3 Background Conditions that affect the selection of an EST in the Caribbean

As already discussed, there are many factors, which help determine what should be considered a sound practice within a particular situation. The following is a summary of the background conditions typical in SIDS. For this summary, information is based on background conditions of the following countries:

Antigua and Barbuda, Barbados, Belize, British Virgin Islands, Bermuda
Dominica, Grenada, Guyana, Jamaica, Montserrat, St. Kitts & Nevis
St. Lucia, St. Vincent & the Grenadines, Trinidad & Tobago, Turks and Caicos

However, generally, most of the technologies presented would be suitable for all SIDS.

The following factors may be used in assessing the background conditions present for individual situations:

Level of Development:
- Economic development, including relative cost of capital, labour and other resources
- Technological development
- Human resource development, in the municipal solid waste field and in the society as a whole

Natural Conditions:
- The physical conditions, such as topography, soil characteristics and type and proximity of bodies of water
- The climate, including temperature, rainfall, tendency for thermal inversions and winds
- The specific environmental sensitivities of a region.

Conditions due to human activities:
- The waste characteristics, including density, moisture content, combustibility, recyclability and presence of hazardous waste in MSW
- The population characteristics such as size, density and infrastructure development

Social and Political Considerations:
- The degree to which decisions are constrained by political considerations, and the nature of these constraints
- Degree of importance assigned to community involvement (including that of women and the poor) in carrying out MSWM activities
- Social and cultural practices.

2.1.4 Guiding Principles For the Application of ESTs and Practices for Waste Management

a) Choice of technology should be based on political, social, environmental and economic factors.
b) Use of risk-based approaches – stringent standards of emission/discharge where risk to human health and environment is high, more lax standards where risk is low e.g. treatment of wastewater versus dilution/dispersion in different waste lines.
c) Stimulation of CBOs or private sector involvement with Solid Waste Management Entity (SWME) support.
d) Regional Strategy – Use of capabilities and capacities of one country to help another.
e) Economic Evaluation of technologies and practices together with cost-benefit analysis and environmental economics.
f) Creation of in-house institutional capacities with allocation of adequate resources to sustain institutions.

2.2 Waste Minimisation

Currently, there is very limited waste minimisation activity in Caribbean SIDS. This is due to a combination of factors including:

- increased demand for imported packaged goods due to rapid urbanisation, with the related rise in standard of living expectations
- isolation of islands from potential markets for recycled materials
- lack of waste minimisation legislation and policies, plans and programmes
- lack of knowledge and therefore enforcement of waste related legislation
- lack of education of the general public

2.2.1 Key Concepts of Waste Reduction:

The key concepts of waste minimisation include:

- Reducing waste at the source,
- Source separation of waste,
- Waste and materials recovery for re-use,
- Re-cycling waste materials
- Reducing use of toxic or harmful materials
- Product life cycle analysis

Waste minimisation is the first line of attack for solid waste management. Waste minimisation reduces the quantity of waste produced, thus reducing all other costs down the line, such as collection, transporting and disposal. Disposal sites last longer and using resources more efficiently reduces costs. In the Caribbean region the islands are small and space is limited. This makes waste minimisation even more crucial to sound MSWM.

2.2.2 Tools for Environmentally Sound Technologies for Waste Reduction

The following "sound practice" tools for promoting waste reduction and materials recovery were identified by the UNEP International Source Book. Each of these tools are evaluated below in terms of sound practice against existing background conditions in Caribbean SIDS:

1. Promote educational campaigns

Education of both government authorities responsible for waste management and the general public is identified as one of the most critical actions necessary in SIDS to help find solutions to solid waste problems. All stakeholders should demonstrate good waste management by example. This education should inform people of the environmental, health and economic impacts of current solid waste generation and disposal habits. Such education will help give public ownership of the problem and should help promote the involvement of the public by providing information on methods of waste reduction, recycling and materials reuse that they can adopt at the household and community levels.

Consideration should be given to public awareness through notification of any changes in policy regarding short-term diversion of recyclables to landfills or any other means of disposal, based on market forces or any other interference that arises.

2. **Study waste streams (quantity and composition),**
   The information derived from waste characterisation studies will enable the setup of recovery and recycling systems, markets for recyclables and to identify problems within existing SWM practices. Where appropriate, the local municipal authority can then take a facilitative/regulatory role. Studies regarding the quantity and composition of waste streams from Caribbean SIDS have been conducted on a regional and national level. The information can be used for managing wastes.

3. **Support source separation, recovery and trading networks**
   Apart from informal source separation, recovery and local recycling / reuse, this is often not appropriate for the majority of Caribbean SIDS, as the quantities of waste are not large enough to support viable trading networks. In addition, the distance between the islands makes delivery of most recovered materials to outside markets uneconomic. However, there is a strong case for separation of items such as paper, cardboard, glass bottles, aluminium cans and steel for reuse or recycling.

Materials Recycling Collection Container (Credit Warmer Bulletin)

4. **Facilitate small enterprises and public-private partnerships by new or amended regulations**
   This is already in place to some extent. Many of these enterprises began as informal salvaging and were able to develop into viable micro and small businesses. These businesses usually focus on glass, paper and cardboard, aluminium, lead acid batteries and iron and steel. This is due in part to the fact that markets for these products exist within the region.

5. **Assist waste salvagers**
   Salvagers play a significant role on a disposal site within some Caribbean SIDS. Solid Waste Management entities should facilitate and provide support for salvaging activities through small enterprises along with general guidelines that regulate salvaging, in order to minimise health and safety problems.

6. **Reduce Waste via legislation and economic instruments**
   After consulting with major stakeholders, where advisable, selective waste reduction legislation on packaging reduction, product redesign and coding of plastics should be advocated. The majority of non-biodegradable waste in Caribbean SIDS waste streams is derived from the importation of packaged goods. Packaging could be reduced through selective waste reduction legislation; however, it is argued that the Caribbean markets are

too small to impose special packaging requirements on distant exporters. The region is at the end of the line for many waste streams generated by manufacturing countries. Special measures, for example surcharges, taxes or deposits, may be justified for plastics, cans or bottles. Funding thus obtained could be used to ensure these materials can be sorted and backloaded to destinations where recycling can be carried out.

7. **Export recyclables**

The Caribbean islands and territories generate a substantial quantity of wastes per annum, which may lend themselves to a structured waste recovery and export recycling programme. According to reports from the Organisation of Eastern Caribbean States (OECS) approximately 45% of the total waste generated in the Caribbean is comprised of glass, aluminium cans, plastics, paper and cardboard; 30% is comprised of green waste with the balance made up of industrial wastes, hazardous wastes, white goods and non-hazardous domestic wastes. While the cost of infrastructure development for establishing waste recycling plants in individual Caribbean islands and territories is high (perhaps with the exception of Trinidad where energy costs are very low) the cost of establishing regional initiatives at waste recovery and recycling may prove to make it a worthwhile approach for dealing with post-consumer wastes which may have some economic value.

For those wastes controlled under the BASEL Convention, to which many of the Caribbean islands and territories are signatories, such an approach will require an amendment to local legislation or side agreements between countries to allow for the export of controlled materials from one country and the import of the materials by another. The advantages of establishing a regional approach to waste recovery and recycling however are immediate in terms of reducing the annual loading to sanitary landfills, reducing the cost of country-wide waste collection programmes and creating new small and medium enterprises with their attendant employment expansion possibilities.

Some waste recovery and recycling is done, primarily by the private sector, but a more structured regional approach will produce enough material to offset the cost of shipment to off-island recycling facilities (be they in or outside of the Caribbean), the cost of expansion of existing recycling plants (within the Caribbean) or even the construction and operation of new recycling plants (for example a plastics or tyre recycling plant). **Table 1** provides information on some of the smaller scale waste recovery and recycling initiatives currently underway in the Caribbean.

8. **Promote innovation**

It is necessary to create new uses for goods and materials that would otherwise be discarded after initial use. Value could be added to recovered waste materials by making the materials into new products. This type of enterprise would require investigation of potential markets. These could be to the local public, to tourists, or for export.

In Caribbean SIDS where waste quantities cannot support recycling or where labour costs are high, value could be added to recovered waste materials by making the materials into new products. This also reduces the reliance on external recycling markets. For example,

Table 1: Recovery and Recycling Initiatives in the Caribbean

Material	Source(s)	Processing Method	Recycling Centres
Paper	Trinidad, Tobago	Baled or Compacted in Super Sacks	Puerto Rico; Continental USA
Plastics (HDPE)	Trinidad	Ground and packaged in Super Sacks	Canada
Cardboard	Trinidad, Barbados, Jamaica, Guyana	Baled	Guyana (limited); Continental USA; Venezuela
Glass	Trinidad, Tobago, Barbados, Grenada, Guyana	Collected in Steel Bins and Ground	Trinidad
Waste Oils	Eastern Caribbean	Bulked in steel drums and re-refined	Trinidad
Vehicle Batteries	Trinidad, Tobago, Barbados, Antigua	Drained and shrink wrapped	Venezuela
Spent Catalysts	Trinidad	Packaged in Super Sacks	Continental USA
Green Wastes	All	Composted	Local Landfills, Households
Used Vehicle Tyres	All	No Recycling Initiatives in Place, some recovery at state owned and operated landfills; retreading practiced in some islands	Local Landfills for holding; retreading in Trinidad, St. Lucia, Jamaica, Suriname, Guyana, Puerto Rico and Dominican Republic.

glass can be crushed and plastics and tyres can be shredded for use as alternative landfill cover, drainage aids and in the construction of temporary landfill roads.

9. **Reducing use of substances which produce toxic, or hazard waste**
   This can be done through public education and awareness, providing information on hazardous or toxic goods and alternative products that are not toxic or hazardous and implementing legislation, which prevents the importation of such products.

10. **Recycling**
    There are significant opportunities for regional initiatives towards a centralised approach to waste recycling. Current examples include the collection of waste oil from the islands of the eastern Caribbean with centralised recycling at the Pointe-a-Pierre refinery in Trinidad, as well as the collection of used batteries and transfer to Venezuela for recycling. Other examples include glass recycling at Carib Glassworks in Trinidad as well as steel and scrap iron smelting at the Caribbean ISPAT Steel Plant in Trinidad.

    These programmes become more economically viable if material supply to the recycling plants increases. Regional initiatives should be encouraged to support more investments in recycling plants for example a centralised tyre recycling facility in one or more of the Caribbean territories.

11. **Reuse**
    Opportunities exist for reuse of non-hazardous wastes as feedstock or material substitutes in the Caribbean. Some examples include the use of crushed stones as aggregate substitutes, and waste plastics for the manufacture of plastic wood and plastic furniture. Other initiatives, for example the use of pelletised tyres for road construction, may be examined in the context of improving environmental benefits and stimulating small or medium sized business ventures.

2.3 Collection and Transfer

Collection and transfer of waste in the Caribbean is usually the responsibility of the Central Governments and/or the various Municipal Governments. Waste is either left at the front gate, or deposited at central transfer points, where the municipality then collects it. Most municipalities manage their own fleet of vehicles or sub-contract these services. In urban areas, waste is swept into piles on the street and collected by a small team of municipal council workers using a shovel, broom and sheet, to throw the waste onto the collection vehicle.

In a number of Caribbean SIDS, a large percentage of waste collection equipment does not operate properly, or is out of service completely due to lack of maintenance, spare parts, or necessary expertise. Any of the different collection technologies suggested will only be sound practice if the necessary preventative maintenance is carried out. Such maintenance includes replacement of worn parts, lubrication, topping up of oil and brake fluid, cleaning and washing.

2.3.1 Environmentally Sound Technology for Collection and Transfer of Waste

The collection vehicle used must be appropriate. The type of vehicle selected should also be evaluated in terms of relative capital cost and labour inputs, maintenance requirements, parts and local availability of technical repair expertise, and suitability to local conditions (terrain, accessibility, manoeuvrability, sea blast etc.)

2.3.2 Principles for Selection of Collection Vehicles

The following principles outlined below represent sound practice, with reference to Caribbean SIDS:

- Select vehicles that use the minimum amount of energy and technical complexity necessary to collect the targeted materials efficiently. Given the high energy costs and relative lack of technical backup in most of the Caribbean countries, a trade off between relative cost of capital and labour is needed.

- Choose locally made equipment, traditional vehicle design and local expertise. There is a long history of vehicles being provided by international aid agencies which are not appropriate for their application, rust in the harsh environment and cannot be fixed when they break down due to lack of parts or local expertise.

- Select equipment that can be locally serviced and repaired and for which parts are available. This is critical in SIDS of the Caribbean to ensure ongoing utilisation from capital investment in the vehicles.

- Choose animal-powered or light mechanical vehicles in crowded or hilly areas or informal settlements, where access by larger vehicles is not possible and cost of operations will be reduced significantly. These types of vehicle are significantly less capital intensive, easy to maintain and have less impact on the environment. However, they use more labour and may be perceived as old fashioned. Animal drawn carts are still being used in Guyana at the village level.

Derelict vehicles (Source: PAHO, Jamaica)

- Consider non-compactor trucks, wagons, tractors, dump trucks, or vans, where population is dispersed, or waste is already dense. These vehicles are lighter, easier to maintain and offer lower capital costs but higher labour requirements.

  Non-compactor trucks in particular should also be considered as an alternative. If used, appropriate covering should be provided to prevent wind-blown litter.

- Procurement through regional initiatives should be considered to help reduce initial as well as operating costs. This was done throughout the OECS countries recently as part of a World Bank Solid and Ship Generated Waste Management Project.

- Consider the advantages of hybrid systems. Where there is a significant difference between the urban and rural areas, or within a compact urban area, a hybrid system with two or more types of collection vehicle could be used. Combining small muscle powered carts for collecting down narrow side streets and alleyways, which then deliver back to a larger truck, or wagon which moves slowly along the main street is one such example.

- Consider compactor trucks in industrialised urban areas where roads are paved and waste is not too dense or wet. Compaction is often seen as more efficient. However, due to the typically high organic content and therefore high density of waste collected in the Caribbean, compaction does not significantly reduce the volume of waste collected. These trucks require more maintenance and are not fuel-efficient.

- Select appropriate/applicable dual collection vehicles to enable simultaneous collection of both organics and recyclables within separate compartments. Where waste separation is a priority, this collection method avoids the need for duplicating the collection runs for different separated materials. However, given the size of such vehicles, access to the generators and manoeuvrability of the vehicle would have to be taken into consideration.

- If collection of waste will only take up one or two days per week, select a machine that can be utilised for other activities during the remainder of the week such as a tractor or tip truck.

- Consider establishment of communal bins where waste may be deposited by waste generators for final transfer to landfills, controlled dumps or waste processing stations. These bins should be serviced regularly.

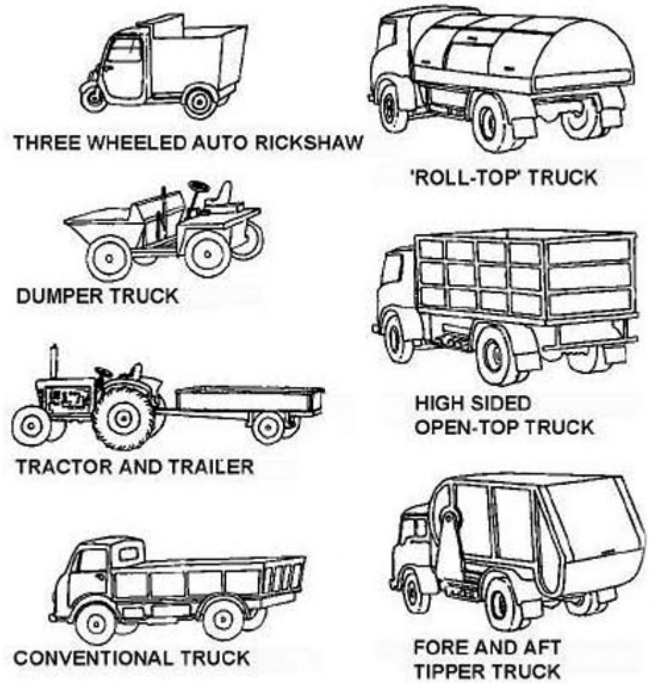
- Consider introduction of stationary waste compactors in areas where population densities are low or ease of access is limited or for commercial, institutional or urban waste.

- Consider the use of containerised waste collection systems where waste recycling initiatives and waste segregation at source initiatives are in place.

The following table details different collection vehicles available:

Table 2: Collection Vehicles Available

Type of Collection Vehicle	Extent/potential use in SIDS	Comment
Small dumper Trucks	Commonly used	based on modified jeep or 4WD, smaller capacity
Fore-and-aft tipper/ Compaction Truck (rear, side and front-end loaders)	Commonly used	enables mechanical loading from transfer bins and compaction of waste. Not suitable in most SIDS
Tractor and Trailer	Commonly used	easily used for other work apart from waste collection
Conventional Truck	Commonly used	can be used for other work apart from waste collection
Highside open-top truck	Is used in some Caribbean countries	suitable for large loads. Could be used in combination with small collectors
Human drawn (litter carts/wheel barrows) Handcart, Animal Drawn cart	Not likely to be used	These types of micro-collection vehicles are inexpensive to build and maintain and therefore are often far more sound compared to motorised vehicles. It is likely to be hard to persuade locals to use these.
Roll On/Roll Off and Open-tray crane trucks	RO/RO used frequently Open tray trucks used in the OECS countries. Crane trucks used in Trinidad and Tobago	RO/RO is a versatile vehicle that allows for deployment and recovery of bins, compactors and other waste containers. Crane trucks are used primarily for the deployment of small bins and may also be used for bulky waste collection



A large variety of vehicles can be chosen for collection. (Credit: UNCHS (Habitat))

2.3.3 Sound Principles for Selection of Set-out Containers

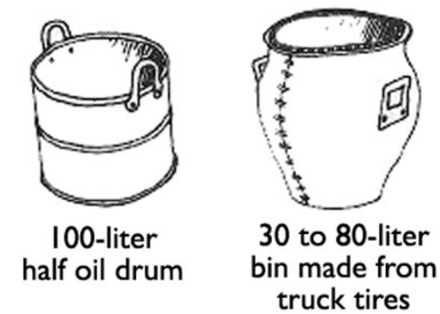
The following principles are recommended when choosing or designing a new system of setout as storage containers:

- Choose containers made of local, recycled, or readily available materials. Examples of containers used within SIDS include 55-gallon steel and plastic drums, 200 litre drums cut in half, or recycled tyre rubber formed into containers.

- Choose containers that are easy to identify, either due to shape, colour or special markings. Set out containers can be made from a wide variety of materials

- Choose containers that are sturdy and/or easy to repair or replace.

- Consider identification of containers with the waste generators name or address. This helps give more of a sense of ownership and participation in the waste collection process.



Set out containers can be made from a wide variety of materials. (Credit: UNCHS (Habitat))

Typical 55-gallon drum used in the Caribbean (Credit: CEHI)

- Choose containers that suit the collection objectives: easy to open and empty, vagrant and animal proof and of sufficient size to hold the expected waste quantities produced

- Where separation of organic waste and or recyclable waste is implemented as part of an

Integrated Waste Management System more than one collection container will be necessary. These containers should be clearly distinguishable e.g. of different size or colour.

- Choose containers that are appropriate for the terrain: on wheels where there are regular paved streets; water proof in areas where rainfall is significant and heavy and squat where there are often strong winds.

- Engage the local businesses and communities. In Nevis, the Authority encourages particular communities with limited vehicular access to build encasements that are located for easy access of collection vehicles. Once these encasements have been approved for safety regulations, the community is given a 360-litre wheelie bin with a lid.

2.3.4 Sound Practice for Route Design and Operation

Collection of waste or recyclables tends to be organised into areas and/or routes. A service area is the region or area that falls under the responsibility of a local government, public authority, or private company. The method, frequency and timing of waste collection can vary significantly, depending on each situation. The most efficient system should be sought to meet the specific needs and conditions that exist in each island and within different areas of each island. An efficient system should aim to cover the necessary service area while using the least amount of capital, labour and time.

Sound principles in collection route design and operation include:

- Timing of collection should be to coincide with times when other traffic on the road is least, to avoid unnecessary delays in collection and for other road users. Consider noise control on equipment as well as householder requirement regarding setting out of waste generated.

- Sizing of collectors appropriately so that the time spent travelling between the source and the disposal site is minimised.

- Speed of vehicle: Where households are far apart (in rural areas), a faster vehicle will be more efficient. Where households are close and compact (in urban areas), a slower, larger capacity vehicle may be better

- Collection frequency should be set to match the expected volume of waste produced, size of containers and local preferences and should keep in mind the health risks that would arise from infrequent collection.

- Kerbside collection of waste from containers set on the kerb or roadside is common.

- Central location: In some situations, requiring households to take rubbish to a central collection point (such as the end of a street), will increase the efficiency of collection. It may also result in the reduction of waste quantities, as households become more aware of the amount they need to cart to the central collection point. However, due to the absence of control over the site, uncontrolled dumping may occur, creating a dumpsite with the associated problems.

- Communal collection points are often used in developing countries. This is where individuals bring their waste directly to a central point (usually a container). This method of collection requires regular servicing by municipal authorities to ensure the central collection site is emptied and cleaned to minimise odours, vectors and prevent animal foraging. There is also more potential for hazardous wastes of unknown origin to be left at the central site. A series of recycling containers could be used at these sites to encourage separation of particular wastes such as glass, paper, aluminium, or organics for reuse. (See also Transfer Below).

- Rules for collection of rubbish should be made clear to all residents and businesses before the new collection system is introduced. These rules should include the times of collection, frequency and list of what wastes can be disposed of and what materials should be kept aside for recycling or reuse.

- Worker's health and safety should be taken into consideration. This includes health and safety training, safety gear and equipment including gloves. Proper tools including shovels and trolleys should be used.

2.3.5 Sound Practice for Transfer of Waste

Transfer stations are centralised facilities where waste is unloaded from smaller collection vehicles near to waste sources and reloaded into larger vehicles (including sea barges), for transport to the final disposal or processing site.

Transfer stations represent sound technology when:

- there is considerable distance between the main waste source and the final waste disposal site.

- they double as a sorting and separation point for recyclable, reusable, hazardous and compostable materials.

- they accommodate the full range of collection vehicles already in use or planned, including private trailers

- they are sized to allow waste to be accumulated if necessary prior to long haul transport.

- operators respect and abide by agreements made with neighbours

- locally made equipment, local designs and local expertise are used where possible

Transfer stations require additional capital costs to set up because of the additional handling of waste. They therefore need to have sufficient supervision and management to ensure the sites operate efficiently and do not degenerate into unregulated dumps.

Transfer stations should be sited appropriately, taking into account the engineering principles and location of the final waste destination, source of the waste and potential impacts on neighbouring properties, remembering that transfer stations can produce significant noise, odour, air emissions and traffic. Where the waste disposal site is far from a village, city or town, a transfer station is often the best way to ensure users have easy access to dispose of waste and that the waste can be efficiently transported.

The following table details different transfer technologies:

Table 3: Transfer Technologies

Type of Transfer Technologies	Potential use in SIDS	Comments
Large truck (over 10 cm/cy) and trailer units.	Used in larger countries (Trinidad & Tobago, Jamaica, Guyana)	For most SIDS applications. Single high sided trucks may be most appropriate.
Sea Barge	Good potential (Antigua/Barbuda, Bahamas, St. Vincent & the Grenadines & Belize)	Where waste is to be disposed of on another island. Presents possible problems with losing waste to sea during the voyage, and when transferring on and off the barge.
Open tipping floor	Least suitable Used in Curacao	More efficient for small volumes of waste. Allows waste sorting, materials recovery and transfer of materials onto different vehicles for different destinations.
Open Pit	Least suitable	Similar to tipping floor but is not ideal for sorting and recovery of materials. Has higher capital and operating costs.
Direct dumping (Satellite collection system)	Only under appropriate management techniques (e.g. Antigua and Barbuda)	Collection trucks unload through hoppers directly into larger transfer trucks. Does not permit sorting and recovery of materials. Requires high equipment maintenance, repair and replacement.

2.3.6 Sound Practice for Keeping Public Areas/Streets Clean

The majority of countries in the world have some type of system in place for keeping streets clean. These include litterbins, mechanical sweepers and manual sweepers. The intensity of such cleaning activities varies depending on the level of use and quantity of dust and other litter that is generated in a particular area. Sound practices include:

- Provide & service litter bins in public areas such as central shopping areas, beaches and outside small food shops and encourage their use through education and enforcement if necessary.
- When planning of sweeping routes take account of the length of route that can be completed in one day, the frequency of sweeping and where sweepings will be deposited.
- Manual sweeping systems

For a manual system, sweepers collect their own sweepings in a small cart/bin and meet a collection vehicle at a centralised point.

Alternatively the wastes could be placed in bags or litter baskets or lined up in piles on the kerb side to be collected by a separate truck.

The status of waste workers can be improved with good equipment. (Credit Chris Furedy)

- Mechanical sweeping systems include four and three-wheeled sweepers and vacuum trucks.
- Mechanical sweepers should only be used where these can be matched appropriately with the service areas.
- In the majority of SIDS, it is likely that manual sweeping will be preferred over mechanical sweeping as the mechanical sweepers require high capital, operation and maintenance expenditure.
- Optimise manual pickup efficiency and health and safety, by providing sweepers with better uniforms, brooms, collector bins and gloves.
- Manual sweepers should be considered in relation to the potential for employment and low labour costs in SIDS.
- Keeping streets clean should be the responsibility of the Municipality. However, there may be a case in the Caribbean for a more decentralised system, where the responsibility is shared with the community.

There are many possible variations in background conditions even within the Caribbean that affect the selection and design of a sound solid waste collection and transfer system. These include terrain, settlement patterns, cultural preferences and waste composition. Designers of waste collection systems need to take these into account and will often need to combine different technologies as they seek to account for the background conditions of the particular location.

2.4 Composting

Composting can be defined as the biological decomposition of complex animal and vegetable materials into their constituent components. Composting occurs best when the ideal conditions are provided to enable bacteria and other organisms to break down the waste materials. This process can either be aerobic (with oxygen) or anaerobic (without oxygen). However, aerobic composting is most common.

For aerobic composting, the ideal conditions are for the waste to be broken into small particles. This is often done using a shredder. Aerobic bacteria require a mix of approximately one part nitrogen, to 30–70 parts carbon food supply, need 40%–60% water in their environment and plenty of oxygen.

In many countries, where there is limited or no space for landfilling and where the soils are sandy and poor in structure, the production of compost from organic waste would have a two-fold benefit. Firstly, it reduces the volume of waste to be landfilled and secondly, it provides a nutrient and structural boost to the soils where it is applied.

Separation and composting organic materials for use as a soil conditioner, fertiliser or growth medium is common practice in many countries to a varying scale and with varying success. Apart from the success stories, there is an alarming number of cases where composting systems have failed completely or operate at only 30% of their capacity. It is often the case in these situations that the composting technologies and or associated management systems installed are inappropriate for the area of application. It is therefore vital that the reasons for these failures are understood and that sound practices are followed for identifying suitable technologies and management systems for composting in the Caribbean SIDS.

Consideration should also be given to non-organic waste that can also be composted. As the composting systems develop, there should also be consideration for the segregation of items in order to produce selective grades of compost. This will affect the economic value of the compost.

2.4.1 Critical Lessons in Sound Composting Practice

The following sound composting practice guidelines have been developed, based on critical lessons learned from historical waste composting systems, which have failed, either completely or in part.

a) The materials to be composted must be compostable in order to produce a marketable product.

- In some SIDS, the waste stream is already up to 50% organic, (OECS 50%, other countries 10-30%) and therefore is ideal for composting.

- The compostable fraction of the waste stream can be enhanced by setting in place the appropriate collection and transfer systems to ensure the compostable waste stream is kept separate.

b) Mechanical pre-processing of mixed solid waste does not work well enough in most cases, therefore source separation or manual separation of inorganic materials should be used.

- In a technical sense, manual pre-processing of mixed waste, works best on small to medium scale systems for highly compostable waste streams

- A disadvantage of manual processing is that it may not be either pleasant or safe for workers.

c) Economic viability depends on three factors. Failure of any of these three can cause the system to fail.

- Unless composting has traditionally been performed, landfilling must be controlled and be sufficiently expensive to make the moderate cost of composting (US $20-40/tonne) competitive with the cost of disposal. For many SIDS, the cost of land area, shipping of waste to centralised landfills and environmental degradation due to landfilling should also be included in this assessment. Until these costs are fully recognised, it is unlikely that composting will be more cost effective than landfilling.

- There must be a market or use for the compost, which should be of acceptable quality. If this market or use does not produce a net income, the Government or Municipality should be prepared to support the difference.

- The waste stream composition has a significant effect on the quality and marketability of the end product. Enhancement of the compostable waste stream by support of source separation and materials recovery of non-compostables, is therefore needed.

d) Technical viability depends on three factors:

- There should not be dependence on mechanical pre-processing. This often breaks down.

- The scale of the composting operation should be dependent on market size, application options and resource potential.

- The entire system from source separation to final screening must be designed as an integrated system to deliver the appropriate inputs and a high quality product output.

2.4.2 Sound Technologies for Composting

The following Tables provide a range of technologies available for composting, from small backyard to large- scale regional systems. In evaluating composting as a technology, the character and type of waste stream to be composted needs to be determined. In this respect, the following points should be noted and investigated further if relevant:

- Waste will need shredding or chipping to reduce size and speed up composting

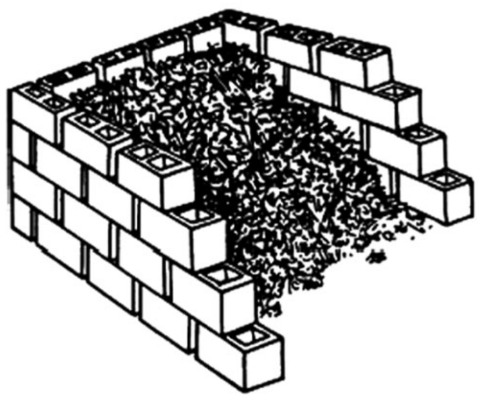
- Kitchen waste can be high in protein from meats, dairy products and some vegetables, leading to unpleasant odours. In this case, combination with high carbon wastes such as yard leaves and lawn clippings, improves compostability

- Accounted for animal feeding which uses kitchen waste. In some Caribbean SIDS, pigs are kept to consume kitchen wastes and provide meat, resulting in reduced quantities of waste being available for composting.

- Domestic Wastewater sludge can be composted. It could be composted in combination with carbon sources such as wood chip, paper and bulking agents to allow oxygen into the compost piles. Such practice requires health and safety precautions to avoid pathogen hazards.

- Manure and animal waste are generally composted in farm applications. This composting is an important aspect of sustainable farming. Such wastes can easily be incorporated into community or larger scale composting systems.

Composting system:
Backyard Composting



(Source: UNEP)

Technology Description:
This is the smallest scale of composting. Composting in the back yard can be done informally, simply by creating a heap of compostable waste, or can be held using bricks, timber or an old drum.

Compostable waste such as kitchen scraps, paper, lawn clippings and garden waste are all placed within the composting container. Once the container is full, a second is used or the first is shifted, leaving the waste to break down over time to form compost. While the first pile breaks down, fresh waste is placed in the second container. The compost needs to be aerated by turning with a fork and water added if necessary to maintain the correct moisture content.

A municipality may issue standard compost bins and educational information which can encourage backyard composting, make it tidier and minimise the potential for problems to occur

Technology: Active pile system; Static-Pile; Vermi-composting

Extent of Use: Only on an informal basis in some countries, encouraged in some countries but not common in others

Operation and Maintenance:
- Relies only on some input by householders to monitor, water and turn the compost to ensure that a good compost is made

Advantages:
- No collection, transfer and final marketing costs
- Low cost
- Encourages public involvement (re. kitchen & garden wastes etc.)
- Social benefits (public education and awareness re. Sustainable development of systems)

Disadvantages /constraints:
- Can cause significant problems with high vermin populations
- Relies on public participation
- Less controlled
- Odours and general public nuisance

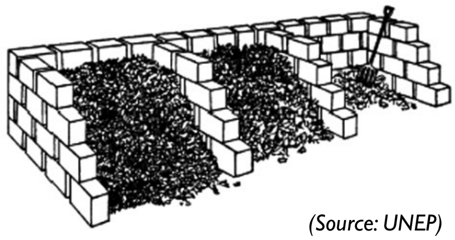
Relative Cost:
- Very low
- Costs for bins and for training

Cultural Acceptability:
- Culturally accepted

Suitability:
- Yes, where houses have sufficient yard space
- Yes, where organic wastes are not otherwise fed to animals
- Yes, where the waste stream contains primarily vegetable matter rather than animal matter
- Yes, because it is an appropriate technology and can be developed locally

Composting system:

Neighbourhood, Village or Business Scale Composting



(Source: UNEP)

Technology Description:

Decentralised composting where quantities of less than 5 tons of waste per day are collected to a central composting point within a neighbourhood, block, or number of businesses.

The site would include a series of concrete or timber bins, which could be alternately filled, composted and emptied.

Alternatively windrows may be used. Support from the municipality with technical advice, turning of compost and emptying would likely be necessary. The site would need good signs and fencing, instructing what is acceptable wastes, current dumping area and to keep unwanted animals out.

This Technology is a sound approach when:

- it is close to the waste source,
- sited beside community gardens, or park reserve
- it has approval from all neighbours
- the waste stream contains primarily vegetable matter rather than animal matter
- it is clearly designated with signs
- there is adequate fencing and
- there is good soil for leachate adsorption

Technology: Static Pile, Active Pile, Non-mechanised windrowing, In-vessel

Extent of Use: Encouraged in some countries but not generally common in all countries/islands

Operation and Maintenance:

- On this scale of operation, collection would typically be up to individual households, with responsibility for co-ordinating, cleaning and maintaining order given to a neighbourhood supervisor, with backup from the municipality to provide technical advice or support for removal of undesired items, or turning of the piles.

Advantages:

- Minimal collection, transfer and final marketing costs
- Low cost
- Encourages public involvement
- Enables more control from municipality

Disadvantages /constraints:

- Can cause significant problems with high vermin populations, animals, insects and odours from site.
- Relies on public participation
- Potential for other non-compostable waste to be dumped at site

Relative Cost: low

- Initial –site set up and for training
- Ongoing -site supervisor, municipality support

Cultural Acceptability:

- May be land-use issues for site chosen

Suitability

- Yes, where houses do not have sufficient yard space for backyard systems and where there is a suitable local community park or garden.
- Yes, where organic wastes are not otherwise fed to animals
- Yes, because it is appropriate technology and can be developed locally

Composting system:
Centralised Composting

Grinder at a Centralised Composting Facility (Source: UNEP)

Technology Description:
Quantities can vary depending on source size. The scale requires waste transportation from the different source points within an urban setting and or neighbouring towns, to a larger centralised site, landfill or incinerator.

Must come under the jurisdiction of the municipality, but could be privately operated. The site would need the area to accommodate vehicles, compost turning, processing, screening and storage.

This Technology is a sound approach when
- technical and environmental assessments, engineering design and formal evaluation of all issues involving all stakeholders is completed
- remediation and compensation to minimise nuisance effects of large scale composting are in place
- separate collection and pre-process system to ensure quality are in place
- a formal system of using and marketing the compost is adopted

Extent of Use: No formal sites exist

Operation and Maintenance:
- Operation and maintenance is high, with increased collection, transportation, and processing equipment needed.
- Level of maintenance depends on the collection and processing technology adopted

Advantages:
- Good control from municipal authority
- More suitable locations outside of town or city
- Economies of scale
- Low input required from individual households apart from separation of compostable wastes

Disadvantages /constraints:
- Higher haulage costs
- Requires large area of land
- Can cause problems with noise, vectors, and odours from large site

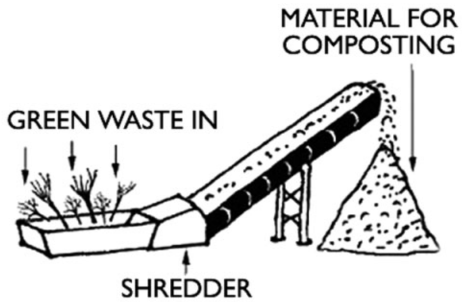
Relative Cost: medium – high
- Initial –site set up, vehicles and for training
- Ongoing high operating, machinery maintenance costs

Cultural Acceptability
- May be land-use issues for site chosen

Suitability
- Yes, where town or city is of sufficient size. Therefore only potential in a few SIDS cities
- Yes, where there is insufficient space for smaller scale systems within the area
- Yes, where appropriate collection and processing technology can be developed and/ or maintained locally
- Yes, where a market is available for the compost

Composting Technology:

Pre-processing Equipment



(Source: UNEP)

Technology Description:

Done to separate non-compostable waste, reduce size of large organic wastes and to blend wastes, to achieve the optimum composting environment.

Pre-processing equipment includes mechanical shredders and chippers. This equipment is often costly, technically intensive and vulnerable to break downs.

This Technology is a sound technology when there is a significant portion of hard - to - compost waste (e.g. coconut husks, palm fronds, green wastes). However, because of high risk of mechanical failure, it is important to choose the appropriate technology to ensure that proper operational requirements are met.

Extent of Use: None known to be used in SIDS.

Operation and Maintenance:

- Operation and maintenance cost is high

Advantages:

- Allows for optimum composting to be achieved
- Produces well blended, small size compost product

Disadvantages /constraints:

- Costly
- High maintenance and vulnerable to breakdown

Relative Cost: High

- High initial –capital costs for machinery
- Ongoing –high operating and machinery maintenance costs

Cultural Acceptability

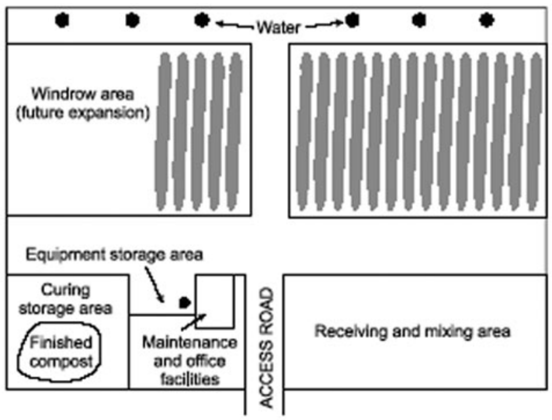
- No known cultural unacceptability.

Suitability

- On a community scale, a shredder, or chipper available for hire from the Council by individual households to reduce the size of coconut husks and palm branches may encourage composting

Composting Technology

Windrow Composting



Windrow Compost Facility Layout
Note: This allows for access and movement of machinery throughout site. Where large machinery is not used, this access is not required.

(credit: UNEP; IETC Report 2)

Technology Description:

Windrowing is a common method of composting, based on storing the organic waste in long rows. The windrows of waste form the basic environment for the waste to compost.

Windrow size is determined primarily from the climate and waste composition. Other factors include the type of aeration used and machinery used for aeration.

Windrows can be open or covered depending on the climate and moisture content of the waste.

Over time, the windrows of composting waste are aerated, turned and mixed as necessary to maintain the ideal composting conditions.

Aeration can either be done using manual or mechanical turning or by static aeration introducing air via a network of perforated pipes within the compost pile.

This Technology is sound when the mechanical equipment used for handling and aerating the compost can be maintained using local expertise.

Extent of Use: Windrowing is most commonly used in developed countries with mechanical aeration by turning rather than static aeration, but not within the Caribbean.

Operation and Maintenance:

- Operation and maintenance needed for aeration machinery.

Advantages:

- Mechanical turning has lower capital costs and machinery is not too specialised
- Static aeration requires less land area

Disadvantages /constraints:

- Mechanical turning requires higher land-use
- Static aeration has high capital cost
- Both require high maintenance and are vulnerable to breakdown

Relative Cost: medium

- Initial–capital costs for machinery
- Ongoing–operating and machinery maintenance costs

Cultural Acceptability

- No known cultural unacceptability.

Suitability

- Windrowing using mechanical turning is likely to be more suitable

The following table summarises the various technologies used within the composting process.

Table 4: Technologies Used Within the Composting Process

Technologies Used in the Composting Process	Potential use in SIDS	Description
Backyard Composters	High Potential	To encourage backyard composting, municipalities, may purchase or subsidise the purchase of compost makers for back yard use; Needs to be integrated with an intensive public education program.
Pre-processing of waste materials	High potential for generating high value products (mulch and wood chips)	Often costly and technically intensive; vulnerable to breakdown; sound practice should minimise the need for pre-processing; done to separate non-compostable waste, reduce size of large organic wastes and to blend wastes to achieve optimum composting environment.
Windrow Systems	Most suitable	The windrows of waste form the basic environment for the waste to compost. Windrow size is determined primarily from the climate, and waste composition; other factors include the type of aeration used and machinery used for aeration. Windrows can be open or covered depending on the climate and moisture content of the waste; Need for leachate management.
Active pile system	May be suitable	Requires manual or mechanical turning of the windrows to aerate piles, provides blending of wastes and prevents excess heat build up; require relatively high land use; has low capital cost and does not need specialised equipment or expertise; specifically developed windrow turning machines require high capital and maintenance cost.
Static Pile Systems	May be suitable	Have higher capital costs than active pile systems; windrows are not turned, but instead rely on air introduced via a network of perforated pipes within the compost pile; require less area, but rely on mechanically pumped aeration; requires high energy
In-Vessel systems	Good potential for some countries.	Expensive to build and operate; higher technology, and therefore more likely to break down.
Tower systems	Not likely	These systems are more expensive than windrowing, but composting is more rapid, resulting in an overall reduced land area requirement.
Vermiculture or vermicomposting or worm farming	May be suitable	A relatively cool but aerobic process by which worms mechanically and biochemically break down organic matter by eating and digesting it; requires considerable labour and careful control of composting conditions; not tested significantly on large scale.

2.4.3 Marketing Approaches for Composting

The role of compost is often (mistakenly) compared directly to that of fertiliser. While compost does have some nutrient value, the most significant value is in conditioning of soils. Compost added to clay or sandy soil significantly increases moisture retention, synthetic and natural nutrient retention and is useful for temperature regulation, preventing erosion and even reducing the incidence of some destructive agricultural diseases.

Sound practice for compost marketing should therefore provide education on the benefits of compost. Methods for such education and marketing include:

- Specifying use of compost in public works and government funded programmes
- Reducing the price of compost for sale
- Giving high profile coverage to business or public applications where the benefits of composting have been proven
- Encouraging high quality compost production

In cases where there is very little suitable material for covering landfill wastes such as on many Caribbean countries, excess, or poor quality compost provides an excellent cover material, which can then support vegetation growth. For the islands where soil materials are very scarce (e.g. Bermuda and the Grenadines) this would be a very sound practice.

2.4.4 Environmental Impacts of Composting Technology

Apart from the positive impacts from composting (decrease in demand for landfill space, potential use for landfill cover, reduction in soil stabilisation chemicals, soil enhancement/rehabilitation) there are also negative impacts. These can include production of odours, carbon dioxide and other green house gases, air emissions from mechanical equipment, potential for high heavy metal content and leachate production.

Leachate contains high BOD and some phenols and surface runoff should be allowed to soak into the underlying soil, or be captured and treated through a sand filter before being discharged to ground, or water.

2.4.5 Conclusions

There are a wide variety of scales of and methods available for composting. Despite a significant number of failed composting facilities, there is now sufficient information to enable proper evaluation of what is appropriate (if at all) in any specific situation.

The major factors to be considered for composting are; siting, input waste stream availability and composition, selection of appropriate composting technology, the scale of composting, market development and lastly, what existing composting practices exist.

In the Caribbean, composting has not been a way of life for residents. However, with increasing pressures on landfill space, available cover materials and waste problems in general, combined with appropriate marketing and education by municipalities, incentives and disincentives, composting could become a significant and environmentally sound waste management technology in the Region.

2.5 Incineration of Municipal Solid Waste

Incineration of Municipal Solid Waste (MSW) may offer an alternative to other forms of disposal when land suitable for landfilling is scarce. Incineration of Municipal Solid Waste substantially reduces the weight (up to 75%) and volume (up to 90%) of waste needing disposal into landfills. In addition, incineration can provide energy for heating or electricity and destroys bacteria and viruses.

The benefits of incineration are most often out-weighed by the significant capital and operating costs, potential environmental impacts and technical difficulties of operating an incinerator.

In particular, the production and venting of such hazardous substances as dioxins from incinerators is a significant concern. Dioxins are very deleterious to health and the environment and can be produced if incineration is not performed at temperatures above 850 degrees Celsius (WHO Fact sheet 1999).

2.5.1 Practices for Choosing Incineration Technology

In assessing the suitability of incineration as a technology for solid waste management, the following factors need special consideration:

- Suitable land for landfilling should be scarce, making incineration cost effective,
- Installation and maintenance of all necessary environmental controls should be included with the incineration technology
- Size and position of the facility should be done to fit in with the other components of the MSWM system.
- Full and clean combustion of wastes is required by having sufficient energy content in

the waste material to achieve the required burn temperature. (This may require the addition of an alternative fuel such as oil, wood, or coal)

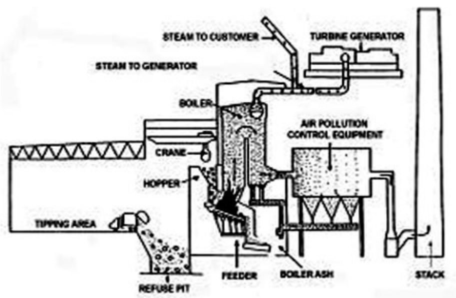
- A suitable nearby energy market is needed to utilise the energy produced

Four different incineration technologies are described in the following tables. These systems are:
1. Mass Burn incinerators
2. Modular Incinerators
3. Fluidised Bed Incinerators
4. Refuse Derived Fuel (RDF) Technology

Apart from these dedicated solid waste incinerators, a certain quantity of municipal solid waste could be burned in existing oil, or new combined fuel electricity generators. Many SIDS already have oil-powered generators which may be able to be adapted in some cases to take some waste, such as hazardous hospital wastes. This is considered in more detail in the section on hazardous wastes.

Incineration Technology:

Mass Burn Incinerators



Cross Section of Typical Mass Burn Facility (credit: UNEP; IETC Report 2).

Technology Description:

This is the predominant form of MSW incineration used. These systems generally consist of either two or three incineration units ranging in capacity from 50 to 1000 tons per day. (i.e. 100 – 3,000 t/day total capacity).

They can accept refuse that has undergone little pre-processing other than removal of over sized items. Waste is deposited on a floor or pit before being continuously fed to a moving grate system that moves the waste through a combustion chamber.

Although versatile, it still requires that household hazardous wastes (certain cleaners and pesticides) be removed to ensure environmental pollution does not occur and that scrap metals are removed for recycling and reuse.

This Technology is a Sound approach when necessary operational and environmental controls can be set and maintained

Extent of Use: Used in Bermuda and Martinique

Operation and Maintenance:

- High levels of operation and maintenance are needed for incinerators.
  If maintenance of environmental controls is not kept up to date, significant human and environmental impacts occur due to air pollution in the absence of stack scrubbers.

Advantages:

(over other incineration technology)

- Refuse requires little pre-processing
- Reasonably convenient and flexible in what they will burn
- Commonly used in developed countries
- Ash has potential as an aggregate provided it is treated
- Potential for partial energy recovery

Disadvantages /constraints:

- High cost
- High level of operation and maintenance required
- Possible adverse environmental impacts
- Ash requires special disposal
- Negative impacts on air quality

Relative Cost:

- Very high (e.g Bermuda: Capital- USD $70M; O&M – USD $5.5M/yr; Capacity – 288 tonnes/day)

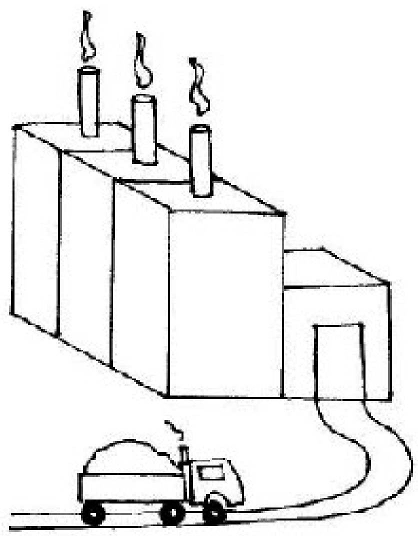
Cultural Acceptability

- Air discharges likely to be unacceptable.

Suitability:

- Only where landfilling area is scarce and
- Where a high level of expertise, for operation and maintenance is available

Incineration Technology:
Modular Incinerators



Technology Description:

Modular incinerator units are usually prefabricated units, with a smaller capacity of between 5 and 120 tons/day. Between 1 and 4 modules are typically operated together to provide up to 400 tons capacity in total, generally supplying steam for heating or electricity.

Modules can be operated continuously, or in a batch cycle depending on the quantities of waste to be burned.

Operate using two combustion chambers. Gases generated in the primary chamber flow to an afterburner chamber, ensuring more complete combustion. Waste is deposited on a floor or pit before being continuously fed to a moving grate system that moves the waste through the primary combustion chamber.

Although versatile, the modular system still requires that household hazardous wastes (certain cleaners and pesticides) be removed to ensure environmental pollution does not occur and that scrap metals are removed for recycling and reuse.

This Technology is a Sound approach when necessary operational and environmental controls can be set and maintained.

Extent of Use: Used in Tortola, British Virgin Islands

Operation and Maintenance:
- High levels of operation and maintenance are needed for incinerators. If maintenance of environmental controls is not kept up to date, significant human and environmental impacts occur due to air pollution.

Advantages:
(over other incineration technology)
- Ideal for smaller communities
- Modular units enable matching of demand
- Can be operated on continuous or batch basis

Disadvantages /constraints:
- Air pollution controls have been found to be inadequate and inconsistent in some cases
- High level of operation and maintenance

Relative Cost:
- Very high but less than other MSW incinerator options

Cultural Acceptability
- Air discharges likely to be unacceptable

Suitability:
- Only where landfilling area is scarce and
- Where a high level of expertise, for operation and maintenance is available
- In smaller sized communities or Islands

Incineration Technology:
Fluidised-Bed Incinerators

An Incinerator in Gibraltar (Credit: Warmer Bulletin)

Technology Description:

Fluidised-bed incineration has been used most extensively in Japan, where plants are typically between 50 to 150 tons per day.

In the fluidised-bed system, the stoker grate is replaced by a bed of limestone, or sand, which behaves like a fluid as air is pumped through it in the high temperatures.

Unlike the other MSW incinerators, the fluidised-bed system requires front end pre-processing of waste where glass and metals are removed and the waste size is reduced.

Fluidised-bed systems operate successfully burning wastes of wide ranging moisture and heat content. Therefore high-energy wastes such as paper and wood can be taken out of the waste stream for recycling and reuse. The Fluidised-bed system is therefore more compatible with high recovery recycling systems, where glass, metal, paper and wood are all removed prior to incineration of the residual waste.

This Technology is a Sound approach when necessary operational and environmental controls can be set and maintained.

Extent of Use:

Used in Trinidad for industrial sludges

Operation and Maintenance:

- High levels of operation and maintenance are needed for incinerators. If maintenance of environmental controls is not kept up to date, significant human and environmental impacts occur due to air pollution.

Advantages:

(over other incineration technology)

- More efficient on smaller scale than mass burners
- Better control giving less residual ash & less pollution
- More compatible with high recovery/re-cycling approach to MSWM

Disadvantages /constraints:

- Relatively new technology, not yet fully proven
- Requires more pre-processing of waste
- More difficult to operate

Relative Cost:

- Very high, savings over other systems inconclusive
- Likely to have lower maintenance costs than other incineration options, but still very high

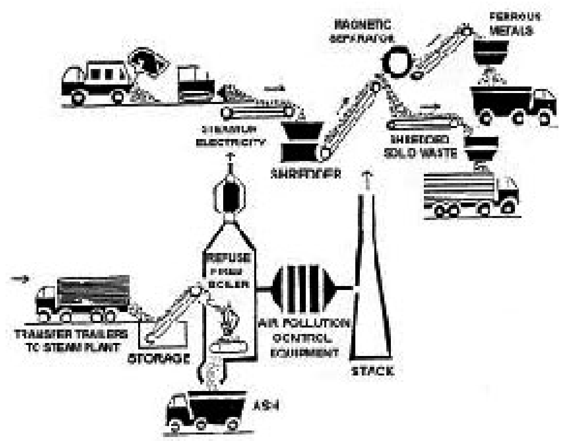
Cultural Acceptability

- Air discharges likely to be unacceptable.

Suitability:

- Only where landfilling area is scarce and
- Where a high level of expertise, for operation and maintenance is available

Incineration Technology:
Refuse-Derived Fuel (RDF)



Cross-section of a typical RDF Facility showing pre-processing, incineration and air pollution control. (credit: UNEP IETC Report 2)

Technology Description:
Refuse Derived Fuel (RDF) can be described in a broad sense as any form of solid waste that is used as a fuel.

RDF is more often used to describe solid waste that has been mechanically pre-processed to produce storable, transportable and more homogeneous fuel for combustion.

RDF can be divided into production and incineration components.

The level of complexity of pre-processing has increased the cost of RDF incineration systems to beyond that of mass burner systems.

RDF pre-processing involves a tipping floor and conveyors, where waste is sorted, screened, trommelled, shredded, hammer-milled and palletised as necessary to suit the waste type and final use specifications

This Technology is a Sound approach when necessary operational and environmental controls can be set and maintained

Extent of Use: Not used in SIDS

Operation and Maintenance:
- High levels of operation and maintenance are needed for pre-treatment and incinerators. High dependence on mechanical equipment can cause problems with breakdowns. If maintenance of environmental controls is not kept up to date, significant human and environmental impacts occur due to air pollution.

Advantages:
(over other incineration technology)
- More compatible with high recovery/re-cycling approaching to MSWM
- Ensures good removal of recyclables and contaminants
- RDF can be used in a variety of burning applications

Disadvantages /constraints:
- Dependent on high mechanical inputs

Relative Cost:
- Very High, due to higher level of pre-processing
- Likely to have higher pre-processing maintenance costs

Cultural Acceptability
- Air discharges likely to be unacceptable

Suitability:
- Only where landfilling area is scarce and
- Where a high level of expertise, for operation and maintenance is available

2.5.2 Environmental Impacts from Incineration Technology

Air emissions and residual ash provide the major sources of pollution from incineration technologies. Air emissions and ash are the two main by-products from any incineration technology. If these by-products are not controlled appropriately, significant environmental impacts are possible.

Residual ash is derived from under the incinerator (bottom ash) and from particulate materials captured from exhaust gases (fly ash). These ashes contain high concentrations of contaminants and therefore require careful landfilling to ensure these contaminants do not leach out, polluting ground and surface waters. Ash is landfilled in separate ash cells within general-purpose landfills, or is placed in purpose built ashfills adjacent to the incinerator site. In Bermuda, the ash is combined and then used to make one cubic metre ash concrete blocks that are used for foreshore reclamation and protection (near the airport).

Air emissions, if uncontrolled, contain high levels of contaminants such as dioxin which is a compound considered within the endocrine disrupters as they mimic the function of endocrine hormones. These affect people by direct inhalation, ingestion through eating exposed foods, or via contact with skin. The level of contaminants in air emissions can be significantly reduced using appropriate "scrubbers," however these require a high level of monitoring and maintenance to ensure continuous effective operation.

Such maintenance requires highly trained technicians and a policy framework that will reliably support the need for necessary maintenance expenditure.

The significance of environmental effects also depends on the location of the incinerator relative to population centres and on prevailing weather and geographic conditions.

These issues should be high on the list of factors taken into consideration when evaluating incineration as a waste disposal technology.

2.5.3 Conclusion

Overall, incineration technology requires a high level of technical input to install, operate and maintain, when operated in an environmentally sound manner. To date, the majority of sound incineration technology application has only been possible in developed countries, where sufficient technical and financial support has been available. Although, there is a need for an alternative to landfilling on a number of Caribbean countries, the suitability of incineration technology should be carefully considered with due regard for technical and financial implications.

2.6 Landfills and Other Methods of Disposal on Land

In a well designed MSWM programme, all other waste management options should be considered before the landfill option is selected. Unfortunately in many cases, the landfill is the only MSWM option used especially when existing landfills already exist. Final disposal alternatives can be broadly divided into four general classifications:

- Open Dumps
- Controlled Dumps
- Sanitary Landfills
- Manual landfills

Open dumping should be discouraged and the trend should be towards controlled dumps and sanitary landfills for final disposal of non-hazardous material only. The concept of secured cells for containment and/or final disposal should be introduced, for example lead/acid batteries and encapsulated wastes.

The following are typical characteristics of the Open Dump:

- Poorly sited
- Unknown capacity
- No cell planning
- Little or no site preparation
- No leachate management
- No gas management
- Only occasional cover
- No compaction of waste
- No fence
- No record keeping
- Allows waste picking and trading
- Environmental degradation
- Associated flooding
- Insect and vector problems

Although common in many SIDS, the majority of open dumps should not be considered sound technology. The other methods are described in Section 2.6.2

2.6.1 Land Reclamation Using Selected Solid Waste Components

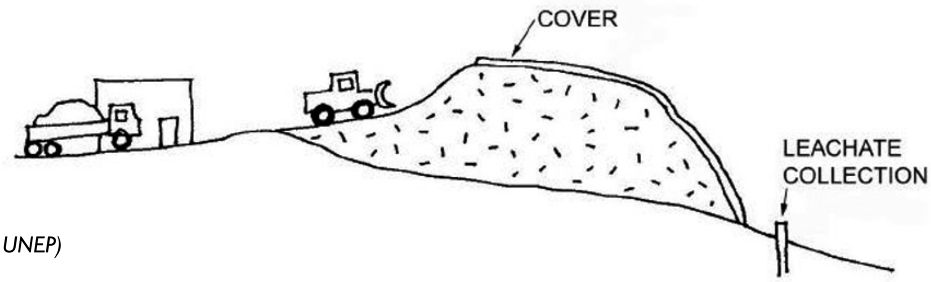
Land reclamation has been used in some Caribbean SIDS and low-lying states for various purposes. In Guyana, for example, solid waste is used to fill-in low-lying areas, which are later used for recreational and other purposes. Principles for sound land reclamation using solid waste include:

- Shelter–Constructing the reclamation where it is sheltered from the force of ocean storms
- Provide adequate protection embankments between the sea or tidal area and the area to be filled to retain the waste.
- Restrict entry onto site
- Remove all hazardous waste prior to disposal
- Provide final cover to waste using sand, or dredging material from the shipping channel
- Provide a vegetation cover as soon as possible after the fill is completed.

2.6.2 Landfill Technology Summaries

Landfill Technology:

Controlled Dump



(Source: UNEP)

Technology Description: A controlled dump generally has the following characteristics:

- Sited with respect to hydro-geology
- Planned capacity
- No cell planning
- Grading and drainage in site preparation
- Partial leachate management
- Controlled waste picking and trading
- Partial or no gas management
- Regular cover
- Compaction in some cases
- Fence
- Basic record keeping

Extent of Use: Limited use but sanitary landfills are becoming more common

Operation and Maintenance: Requires a trained dedicated operator to ensure the management procedures above are carried out.

Advantages: (over open dumps)
- Less risk of environmental contamination
- Permits long term planning
- Better rainfall runoff
- Extended lifetime
- Controlled access and use
- Information
- Materials recovery by waste pickers allowable
- Higher vector and rodent control
- Odour, dust and litter control

Disadvantages /constraints:
- Slower decomposition due to less moisture
- Increased costs and maintenance
- Possible loss of materials recovery due to application of cover material
- Potential for methane build up in the absence of venting
- Absence of cover material
- High risk of contamination compared to sanitary landfill method

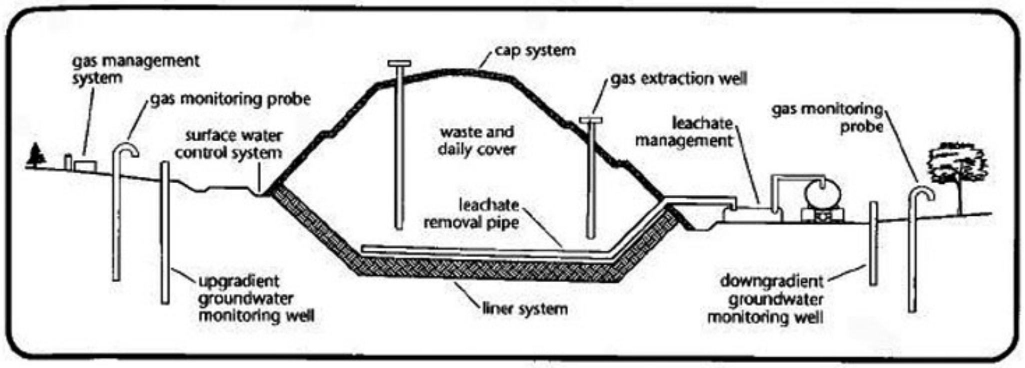
Relative Cost:
- More expensive than open dumping, due to higher level of environmental protection
- Higher operating costs due to compaction, covering and other landfill management procedures listed above.

Suitability:
- Applied as a temporary measure in some countries where sanitary landfills are being considered and/or constructed.

Landfill Technology:

Sanitary Landfill

Typical schematic of a state-of-the-art landfill



(credit: Paul C. Rizzo Associates)

Technology Description:

A sanitary landfill generally has the following characteristics:

- Site chosen based on environmental risk assessment
- Planned capacity
- Designed cell development
- Extensive site preparation
- Record kept of waste volume, type and source
- No waste picking and trading
- Full leachate management
- Full gas management
- Daily and final cover
- Compaction
- Fence and gate

Extent of Use:

- Presently operational in St. Vincent, St. Kitts, Nevis, St. Lucia, Antigua, Barbados, Bahamas. Efforts are being made to have sanitary landfills constructed in other countries.

  Gas capture and leachate treatment operations are not in place at some sites. Landfill gas management system costs are high thus decision to include should be based on assessment of risk factors for a particular site.

Sanitary landfill under construction, St. Lucia (Courtesy: C. Jules)

Operation and Maintenance:

- Staff to include Landfill Manager, Site Supervisor, Landfill Technician, Weighbridge Operator, Site Labourers, Security Officers. It is proposed that all technical staff become certified.
- Ground and surface water and leachate and gas monitoring. Recommend that a regional arrangement be utilised.
- O&M should be guided by policy and regulatory guidelines.
- Operational plans should be in place.
- Landfill gas management systems are costly and thus a decision to include them should be based on an assessment of risk factors for a particular site.

Advantages: (over controlled dumps)	**Disadvantages /constraints:**
• Lower risk of environmental contamination • Permits long term planning • Controlled surface water runoff/reduced infiltration • Extended lifetime (10-15 yrs.) • Secure access and use • Improved information/data management • Reduced health risks to site personnel and users.	• Longer siting process • Slower decomposition due to less moisture • Increased costs, operational and maintenance • Possible loss of materials recovery due to application of cover material • Waste diversion/source separation required • Competitive use for top soil

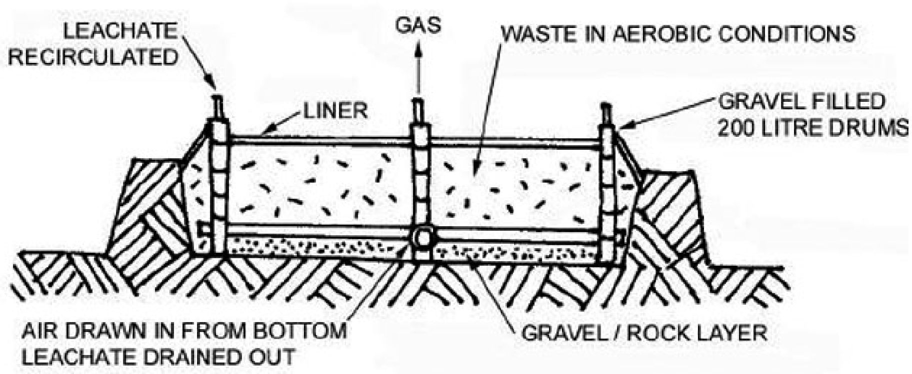
Relative Cost: (compared to controlled dump)

- Most expensive technology, due to higher level of environmental protection and infrastructure development.
- Higher operating costs due to compaction, covering and other landfill management procedures listed above.

Suitability:

- Yes, for new sites where the financial, management and technical resources are available for design and operation.
- Where suitable sites are available.

Landfill Technology:
(Semi-Aerobic Technology; e.g. Fukuoka Method)



Technology Description:
The Fukuoka Method exploits air convection due to temperature differences to draw air through the waste. It is constructed simply by building up an earth embankment around a site to create a shallow, enclosed disposal area. A perforated pipe network is then laid centrally along the site and embedded in coarse gravel or rock for protection during filling and to aid air circulation and leachate drainage. At the end of every pipe branch is erected a perforated stand pipe to allow air intake to the landfill and leachate re-circulation. The vertical stand pipes are protected by standing 200 litre oil drums over the stand pipes and backfilling with rock. Waste is then spread over the pipe work using a bulldozer for spreading and compaction. Leachate is collected from the drains, retained in a pond and re-circulated.

Extent of Use:
Not used in the Caribbean SIDS but widely used and accepted in Japan.

Operation and Maintenance:
- Requires reasonably high operation and maintenance input.

Advantages: (over other landfill options)
- Less risk of environmental contamination
- More rapid waste decomposition
- Aerobic conditions minimises the production of odours, and nitric acids, improving leachate quality
- Site regeneration is more rapid, with final use as recreation and parks
- It is cost effective compared to anaerobic landfills
- Reduces production of greenhouse gases
- Requires less area
- Ensures controlled filling

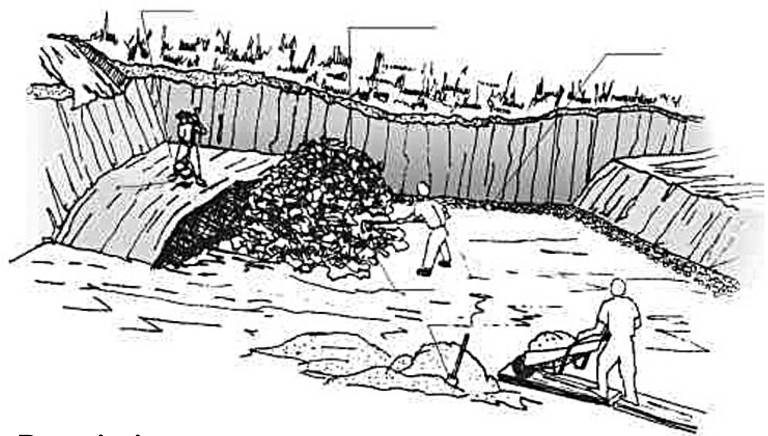
Disadvantages /constraints:
- Requires a medium level of O & M

Relative Cost:
- More expensive than open dumping, due to higher level of initial capital setup costs.
- Higher operating costs due to compaction, covering and other landfill management procedures listed above.

Suitability:
- Yes, for new sites, this method will take up less space than current hap-hazard disposal sites.

Landfill Technology:

Manual Sanitary Landfill



Technology Description

The manual sanitary landfill (< 15t/day) is adequate for small communities (less than 30,000 inhabitants) which, in view of the quantity and type of waste produced and their precarious economic situation, cannot afford to buy heavy equipment because of high operating and maintenance costs. The term "manual" refers to the fact that the task of compacting and confining the waste can be carried out by a team of labourers using hand tools.

Heavy equipment is required only to prepare the site (construction of the internal road, preparation of the supporting base or digging of trenches and extraction of cover material), which means that small communities with scanty resources are able to dispose of hygienically the small amount of waste they produce, employing unskilled labour.

A manual landfill can serve two or more towns and can eventually become a regional solution, that is, able to offer the service of final disposal of MSW to several nearby towns.

Extent of use: Cuba (as well as Colombia, Peru, Nicaragua, El Salvador).

Operation and Maintenance:

- Acquisition of tools.
- Purchase of safe equipment for the workers.
- Closure of the open dump(s).
- Permanent maintenance
- Preparation of the annual budget.

Advantages (over other landfill options):

- More adequate for small communities.
- Control risks to the health and environment.
- The initial capital investment is lower than that required to establish incineration plants or composting facilities for waste treatment.
- It creates employment for unskilled labour, which is available in abundance in developing countries
- Its location can be as close to the urban area as the existence of available sites permits, which reduces hauling costs and facilitates supervision by the community.

Disadvantages/constraints:

- The term sanitary landfill is associated with open dump.
- Citizens' evident distrust of local administrations that do not guarantee the quality or the sustainability of the work.
- The high risk of becoming an open dump mainly because of a lack of political decision to invest the necessary funds for its correct operation and maintenance.

Advantages and Disadvantages/constraints: continued on next page...

Advantages and Disadvantages/constraints: continued from previous page...

- It allows land considered unproductive or marginal to be recuperated, making it useful for constructing parks, recreational facilities, green areas, etc.
- A sanitary landfill can start operating in a short time as a waste elimination method.
- It is considered flexible because it can receive greater additional quantities of waste with a small increase in personnel.

- It can cause a long-term environmental impact if the necessary precautions are not taken in the selection of the site and if mitigation measures are not applied.
- Usually it cannot receive hazardous waste.

Relative Costs:

- Implementation: US$ 10 - 20 per inhabitant or US$ 50–100 per family (depending on access road to the site, topography, etc.)
- Operation: US$ 0.20–0.60 per family/month (depending on availability of cover material, cells construction, control of leachate and gases, etc.)

Suitability:

- The manual sanitary landfill is a technically and economically feasible alternative, benefiting urban and rural populations of less than 30,000 inhabitants who have no way of acquiring the heavy equipment they would need for constructing and operating a conventional sanitary landfill. This is also a good alternative for the marginal areas of some cities.

2.6.3 Sound Practices for Landfill Technology

In planning a new landfill, the following sound practices should be adopted. These sound practices should also be used as guidelines when evaluating existing landfills:

a) Appropriate siting and sizing
b) Leachate management and environmental impact minimisation
c) Gas management and risk reduction
d) Secure access and recording of waste inflow volumes and character
e) Data Management
f) Compaction and daily cover
g) Documented operating procedures and worker training and safety programmes
h) Establishment and maintenance of good community relations
i) Adherence to operations plans
j) Closure and post closure planning

Integrated Solid Waste Management is a practice using several alternative waste management techniques to manage and dispose of specific components of the waste stream. Some of these alternatives include waste minimisation (source reduction, recovery and recycling), composting, energy recovery and landfilling. Given the increasing cost of solid waste management (collection, processing and disposal) technologies and methods, the Caribbean needs to continuously explore a series of combinations of techniques and programmes that would reduce the demand on limited natural and

Sanitary landfill synthetic lining being installed, Bahamas (Courtesy: H. Sealy) acquired resources and at the same time ensure sustainability of the selected systems within the limits of their economies. Emphasis needs to be placed on waste minimisation so as to divert a significant volume of waste to be disposed by landfilling. Some practices could include deposit-refund systems on selected items, controls on the level of packaging of imported items and the use of up-front disposal fees on non-biodegradable special waste items such as tyres and derelict vehicles. This hierarchical approach to waste management allows for better comprehensive monitoring of system costs, operational effectiveness and public acceptance.

Technologies for each of these sound practices are described in more detail in the following sections.

a) Siting and Sizing

Siting of a landfill is the first and most difficult stage. When siting a landfill, the following should be considered:

- Capacity (determined from predicted waste quantities and desired design life; Ideally 10-20 years)
- Public involvement (to ensure all issues and concerns are raised and accounted for)
- Hydro-geology (Ideally clay and/or impermeable rock will minimise the chance of leachate coming into contact with groundwater)
- Topography
- Suitable cover material (needs to be available nearby in sufficient quality and quantity)
- Access (should be reasonably close to waste source if possible to minimise haulage costs, however environmental impact factors should be of higher priority in siting. Transfer stations are sound practice where landfills are too far away from the waste source.)
- Proximity to airports (as far away as possible to minimise bird strike)
- EIA approval to include environmental hazard and risk assessment

In addition to the above, landfills should not be sited in very windy areas, near existing services such as drinking water, ground or surface sources, reticulation, sewer, gas or electrical lines, or near residential areas, social venues, schools etc.

b) Leachate Management Technology

Leachate is formed as rainfall soaks through the waste and as the waste decomposes. The leachate drains to the bottom of the landfill, taking with it potentially toxic contaminants in soluble form. To minimise the potential for leachate to escape into the surrounding surface or ground waters, the following technologies are used:

An impermeable liner below the waste. This can be either formed from in situ natural materials or clay of bedrock where these are of sufficiently low permeability (usually $< 1 \times 10^{-9}$ m/s), or be a constructed liner made from clay and/or synthetic materials. Modern liner designs combine natural soil layers and synthetic liners into a composite liner to utilise the best properties of both. Clay liners are thicker (typically 600 –900 mm) and so more resistant to damage by sharp objects in the refuse. The clay can also act to absorb contaminants in the leachate. The synthetic plastic liners (e.g. 1-2 mm HDPE) are very impermeable but being thin are more susceptible to damage.

Where natural clay soils are unavailable (e.g. on atolls or in volcanic countries) the clay layer can be replaced with a synthetic layer of a GCL (Geosynthetic Clay Liner). A GCL is a manufactured liner combining bentonite powder and geofabrics into a thin but highly impermeable layer – a 10-12 mm GCL layer has the same seepage rate as a 600 mm clay layer. A GCL however does not have the same absorption capacity as a clay liner.

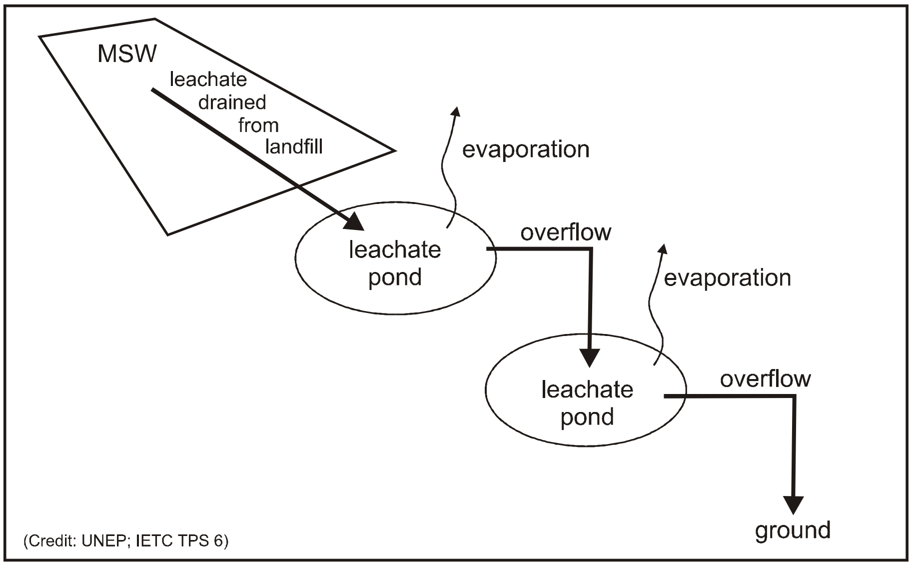
Liner systems need effective protection by sand or geofabric layers to prevent damage from the overlying drainage layers and compacted refuse. Proper design of leachate drainage and collection systems is required to minimise the depth of leachate stored above the liners and so reduce any leakage to a minimum.

Minimise entry of rainfall by capping of waste in controlled cells and placing a final capping liner when the landfill is completed. Rainfall infiltration can also be reduced by grading the landfill such that water drains off the surface. Where this is done, stormwater runoff should be captured in a pond and allowed to settle prior to discharge.

Leachate collection. Leachate collected by a liner will accumulate and possibly leak if it is not collected and removed using a collection system. Leachate can be collected by either placing a pump sump at the lowest point on the liner, or by grading the base of the landfill so that leachate flows by gravity out of the landfill. To increase drainage efficiency, perforated pipes are placed and/or coarse gravel layer is placed above the impermeable liner. Collected leachate is then discharged into a wastewater treatment system or ponds for treatment. Gravity drainage is the most sound if this is at all possible, as it avoids the need for pumping systems that have higher maintenance costs, due to the corrosive nature of the leachate.

Leachate Re-circulation is not really an option for the "disposal" of leachate, however it is effective at reducing the strength of leachate and so can make subsequent treatment steps easier. In a hot dry climate it may also be effective at reducing the overall volume of leachate requiring treatment and disposal through increased evaporation.

Re-circulating of leachate over the waste in landfills has been shown to increase the production of methane gas, which is beneficial if the gas is being harnessed for energy. It also has the effect of accelerating decomposition of the landfill waste. Although leachate recirculation is a relatively new technology, it is a promising technology for managing leachate where landfills have suitable liners and where gas collection for energy production is proposed. Re-circulation does increase the chance of leakage through the liner, clogging of the drainage system and can cause increased odours.



Cascading Leachate Ponds

Drying of waste to reduce leachate is a cheap alternative to help reduce the quantity of leachate where dumps or landfills do not have liners. This is done by partially drying waste at the transfer station prior to placing in the landfill.

Grading of landfill base. Where pre-drying is impractical and there are no appropriate soils or rock for under liners, an increased grading of the landfill base, combined with a well distributed leachate collection system will reduce the quantity of leachate leaking into the underlying groundwater. This will add to the cost of the landfill, but may be cheaper than importing a suitable clay liner material at high cost.

Gravity Collection and Evaporation. Leachate drains by gravity to a lined waterproof pond down stream, where it is allowed to evaporate. A series of ponds could be used as detailed below to allow evaporation and natural biological treatment. These ponds need to be sized based on a hydraulic balance of leachate, evaporation and rainfall.

Note: Leachate ponds need to be lined to prevent soakage into the ground.

c) Gas Management and Risk Reduction

Landfill gas is a mixture of methane and carbon dioxide produced by the decomposition of organic matter in the MSW. Landfill gas is highly flammable and is heavier than air. It therefore tends to collect in the hollows and basements causing a significant hazard through explosions and displacement of air causing suffocation.

In countries having open dumps, the generation of methane gas is likely to be minimal. In addition, any gases generated are likely to freely escape from the dump and be dispersed by sea breezes.

Where landfill gas is a problem, a low cost passive system to handle landfill gas consists of a number of buried vertical perforated pipes that use natural pressure of the landfill gas to collect and vent or flare gas at the surface.

Alternatively, for a fully lined landfill, a more active system is to collect the gas using a network of pipes and pumps and process it to use for heating or electricity generation. This is more risky and requires high technical input; therefore it comes at a higher price than the passive system.

d) Secure Access

Fencing of landfills should be designed to restrict unauthorised access and to keep vermin and animals out. A vegetative hedge should be planted. This helps screen the landfill visually and reduces wind nuisance. A staffed gate should be at the point of entry.

e) Data Management

Appropriate data sheets must be designed to allow weighbridge operators to make entries of the quantities and types of all waste material inflow. Provision must also be made on forms for the identification of tippers and salvagers.

Waste inventories must also account for the volume and types of waste materials entering special (dedicated) cells requiring treatment before final disposal.

Data sheets should be designed for daily entries and compiled into weekly and monthly recording forms. All information will then be compiled and fed into established solid waste management information system databases.

f) Compaction and daily cover

Compaction of waste ensures that the maximum quantity of waste can be deposited in the designed landfill area, thus optimising the life of the landfill. However, full waste compaction requires the use of heavy mechanical compactors, which increases initial capital and on going operation and maintenance costs. Therefore, where finance and technical inputs are not available, the use of specialised compaction machinery is not sound. However, a lesser extent of compaction may be possible using a tractor and trailer, or a bulldozer.

Landfill Compactor
(Credit: SPREP 1998)

Daily cover is used to prevent rubbish from being exposed where it can be blown by the wind, accessed by birds, flies and rodents and where it causes odours. Daily cover also aids the runoff of surface water during rainfall. Daily cover of waste is generally considered sound practice, however, where cover is not available and in cases where the waste does not attract flies and birds it may be considered sound not to use daily cover material.

Dredge material from harbours and rivers has in some cases, such as Antigua and Trinidad, been used as fill material. The use of fines from quarry operations and compost as landfill cover may be sound practices where these do not adversely impact on the environmental source lagoon or harbour marine environment.

g) Documented Operating Procedures and worker training and safety programmes

To ensure consistent and proper operation and management of the landfill over the life of the landfill (anywhere from 5 to 25 years or more), clear documentation of operating procedures is necessary. In addition, worker training, health and safety programmes will ensure that the landfill is operated in an environmentally and human safety friendly manner. Worker training and occupational health and safety programmes should also include preventative procedures such as vaccinations against hepatitis and leptospirosis as well as frequent testing and monitoring.

h) Establishment and maintenance of good community relations

One of the primary impacts from a landfill operation is the impact on direct neighbours and on the local community. It is essential that good relations be established with these groups to ensure these impacts are understood and dealt with before or as they arise. The level of community involvement can have a significant impact on the overall success of the landfill operation and the overall solid waste management strategy.

i) Closure and post closure planning and use

Once a landfill has been filled to capacity, a final layer of cover is necessary to seal the fill and provide a final finish. The final levels, grade and finish need to be set according to the proposed after-closure land use. Although a steep final surface grade will minimise the amount of rainfall infiltration and thus quantity of leachate produced, the proposed future land use may require a flat surface, for example, a sealed carpark, recreation or sports field.

2.7 Special Wastes

2.7.1 Tyres

Tyres require high energy input to be able to recover any of the materials for reuse and this process is hazardous. In addition, tyres do not sit well in landfills, where they tend to "float" to the surface, making it difficult to maintain the soil cover above the waste.

Tyres baled in a Caribbean island (Source: PAHO)

The following are sound practices for management of tyres:

Reuse: re-treading, shredding and grinding for use in road paving materials, cutting them up for use as padding in playgrounds, buffers, rubbish containers, door mats, growing potatoes in tyre stacks, or swans. It should be noted that tyre materials may be carcinogenic and therefore workers should avoid dust and buffings when working with tyres. Baling is presently done in Antigua and Jamaica, used as retaining walls in St. Vincent and the Grenadines, as structured artificial reefs in several countries and as crayfish traps in Belize, flower and other plant beds in Barbados and for coastal erosion prevention at the airport in Bermuda.

Thermal destruction in Cement Kilns with energy recovery. Such kilns require adapting to take the tyres, however, once this is done, this has been found to be a good method of destroying tyres. Trinidad, Barbados and Jamaica have cement kilns which could be utilised in this way. This is under research in Trinidad.

Processing in pyrolytic ovens. This is only sound practice when gas emission controls are used to trap harmful organic vapours. It is generally expensive and requires technical input.

2.7.2 Construction and Demolition debris

Demolition wastes largely consist of cement, bricks, asphalt, wood and other construction materials that are largely inert. Where construction and demolition waste contains hazardous materials it should be treated as hazardous waste. The private sector should be encouraged to reuse this debris as aggregate material. These wastes can take up a large volume if disposed of with other wastes. However, they are not usually suitable as ordinary fill material.

The following are sound practices for the disposal of construction and demolition wastes:

- Have all hazardous materials segregated during building demolition (i.e. fluorescent tubes, asbestos, PCBs, CFCs, etc.)
- Reduction of waste through promotion of inventory control and return allowances for construction materials.
- Selective demolition where specific recoverable and reusable materials such as timber, windows and bricks, are removed prior to demolition of the building structure.
- On-site separation using multiple containers for different waste materials
- Crushing, milling and reuse of secondary stone and concrete materials for fill, or road building materials.
- Reuse of rock, brick and concrete materials for land reclamation, shore erosion protection and sea walls.

2.7.3 Ship/Airport Generated Waste

Air and sea travel throughout the Caribbean continue to increase. This increasing trade brings with it increased generation of solid wastes which require disposal. Within the Caribbean some countries have satisfied the MARPOL 73/78 convention that places responsibilities on each country to provide port reception facilities for waste generated from ships.

The Caribbean needs to develop management plans for the effective storage, collection, transportation and disposal of ship-generated waste. Precaution should be taken in handling ship-generated waste to protect the environment and the health and safety of the personnel.

2.7.4 Bulky Waste

Bulky waste is a major challenge to municipalities. If not collected and managed properly, these wastes are usually dumped and cause great health problems. Also, these wastes cannot traditionally be collected using compactors or small collection vehicles. As a result, separate collection days and times are usually maintained. However, there is the continual challenge of landfill space as these wastes usually occupy a lot of space. Re-use programmes and composting systems could be considered to manage some of these waste types.

2.7.5 Derelict Vehicles

In Bermuda there are provisions for derelict vehicles. The oil and gas are drained and the battery removed. The vehicle is then transported to the landfill Site. There is however still a space challenge. In Trinidad and Tortola, BVI, programmes have been set up so that the vehicles are dismantled, cut up and then baled for recycling.

2.8 Information Sources for the Caribbean

- Caribbean Environmental Health Institute (CEHI)
- Organisation of Eastern Caribbean States/Environment and Sustainable Development Unit (OECS/ESDU)
- Caribbean Conservation Association (CCA)
- Pan American Health Organisation (PAHO)
- United Nations Environment Programme (UNEP)
- United Nations Development Programme (UNDP)
- Inter-American Development Bank (IDB)
- Caribbean Development Bank (CDB)
- National Environment and Planning Agency of Jamaica (NEPA)
- Environmental Management Authority of Trinidad and Tobago (EMA)
- Environmental Protection Agency of Guyana (EPA)
- Caribbean Water and Wastewater Association (CWWA)
- Wider Caribbean Solid Waste & Recycling Alliance (ReCaribe)

Contact details for these organisations can be found in section 5.0

3.0 HAZARDOUS WASTE TECHNOLOGIES

3.1 Introduction

Hazardous wastes are defined as waste materials that cause an immediate or cumulative hazardous potential to humans and or the environment. These wastes could be toxic, poisonous, corrosive, flammable, infectious, or explosive. Hazardous wastes therefore need special handling, treatment and disposal because of this hazardous potential. Reference should be made to listings in the Annexes of the Basel Convention and other international treaties and conventions.

As for other wastes, hazardous wastes should be managed using the same integrated waste management hierarchy. Those are waste minimisation, resource recovery, recycling, treatment and final disposal.

The following is a list of different types of hazardous wastes found in Caribbean SIDS:

a) medical waste to include radioactive waste, (from hospitals, clinics and laboratories)
b) household and agricultural hazardous wastes, (e.g. oil-based paints, paint thinners, wood preservatives, herbicides, pesticides, cleaners, used motor oil, antifreeze and batteries)
c) used oils
d) batteries
e) asbestos
f) human excreta, sewage sludge, septage and slaughterhouse waste
g) industrial waste
h) e-waste (computers, PDAs, cell phones, etc.)

Effective management of the above hazardous wastes depends on a clear understanding of their potential for and mode of impact on human health and the environment. Once this impact is understood, appropriate management practices can be put in place for handling and disposing of the wastes.

Hazardous wastes are currently often handled poorly. Where incinerators have been installed for medical waste, these often have broken down.

The development of a national integrated hazardous waste management plan should consider:

- A regional approach to hazardous waste management
- Proper waste management planning (legislation, institutional strengthening, training, public eduction/awareness etc.)
- Conduct of a hazardous waste inventory
- Waste tracking

- Removal of existing stockpiles of persistent organic pollutants (POPs), such as PCB's, pesticides, solvents and waste oil, possibly for exportation.
- Collection and storage in concrete containers
- Government agreements with oil companies to take back used oils.
- Increase education to help locals distinguish between general and hazardous wastes

3.1.1 Export of Hazardous Waste

Where hazardous wastes cannot be disposed of appropriately in a country, they should be stored appropriately until such time that they can be backloaded to be disposed in another suitable country. Suitable storage facilities should be:

- Secure from unauthorised access
- Weatherproof to keep waste dry and prevent leaching to surface or groundwater
- Bunded to provide secondary containment where spillage or leakage does occur.

A receiving centre should be an approved HAZMAT facility or a secured storage cell at an in-transit location. Consideration of options for export of hazardous wastes should be done in accordance with the Basel Convention and other international relevant treaties governing the movement of wastes.

The "Basel Convention on the Control of Trans-boundary Movements of Hazardous Wastes and their Disposal" (March 1989), provides a detailed list of wastes that are hazardous and lists technologies that may be used to manage these wastes. It also sets out a convention for sound management of hazardous wastes and in particular the control and minimisation of movement of these wastes between different States, or boundaries.

3.2 Medical Waste

Medical waste requires careful handling and disposal as it may contain high levels of pathogenic or infectious/radioactive waste, sharps and hazardous or toxic substances such as cleaning agents, or discarded medications. In Caribbean SIDS, these wastes are often disposed of in a haphazard manner in open dumps and crude incinerators, where they are not adequately processed or fully secured from access by the general public, or children playing in these areas. In the Turks and Caicos Islands (TCI) the medical waste is managed by the Vector Control Officers within the Environmental Health Department. This is done under the supervision of an Environmental Heath Officer (EHO). There are also private sector initiatives that provide on-site incineration/processing in some countries. Centralised autoclaving is also done in St. Lucia. Policy documents and legislation have also been developed in Jamaica, St. Lucia and Guyana.

Sources of waste include hospitals, health care facilities, doctors' offices, tattoo parlours, funeral homes, medical laboratories and veterinary offices.

WHO and CEHI have significant information resources available on handling and disposal of medical wastes. The WHO web site http://www.who.org is worth a visit, or information can be obtained from WHO, in Geneva Switzerland (e-mail: publications@who.ch).

Sound practices for disposal of medical waste should include the following:

Source separation within the health care facilities to include:
a) administrative waste: separate harmless waste such as paper, cardboard and food scraps, for reuse and recycling,
b) infectious and hazardous wastes using special collection containers which are colour coded, or clearly different for appropriate disposal.

WHO has reported that model medical-waste-management programs in India and elsewhere have shown that segregation and reduction practices can minimise much of the waste that needs to be safely disposed. These programs are successful in reducing the amount of potentially infectious waste, reducing other medical wastes, educating staff and developing local policies to deal with these issues. The potentially infectious part of the waste is much less than 10% (some estimates are 1-3%). Therefore, if waste management programs are based on good segregation, they will greatly reduce the waste problem.

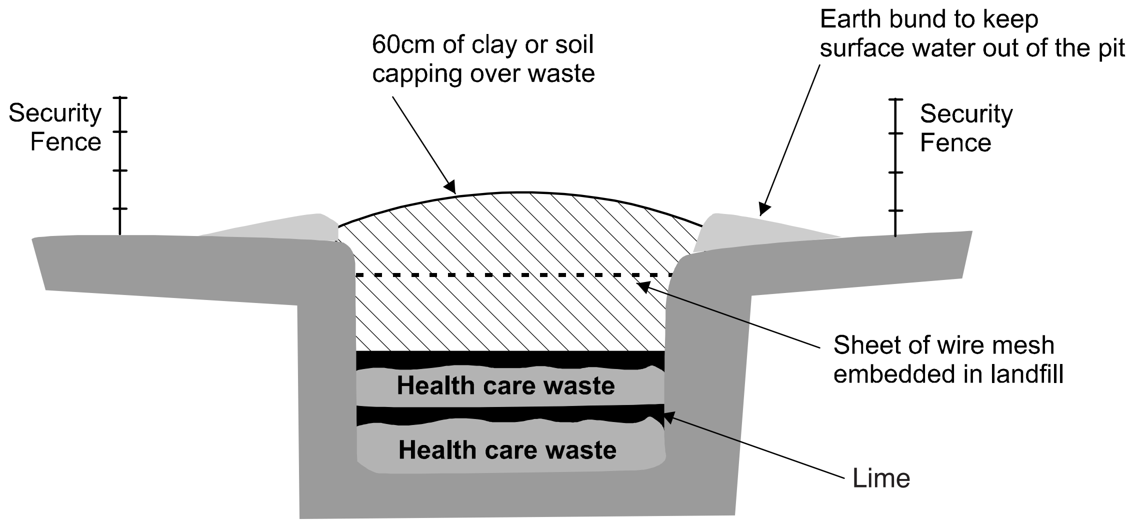
Set Procedures and equipment for Handling and Transportation to ensure wastes are handled in a sound manner to minimise risk of exposure, for example placement of all sharps in secure containers as appropriate, for their final disposal and provision of appropriate clothing, collection containers and vehicles for handling the wastes collected.

Take back systems, where vendors or manufacturers take back unused or out of date medication for controlled disposal

Tight keeping of inventories, to avoid wastage

Piggy back systems, where nursing homes, doctors offices and clinics can funnel their waste through the main hospital waste system.

Treatment of infectious waste by disinfection. Disinfection can be done using autoclaving (Steam sterilisation), shredding followed by chemical disinfection or microwaving and irradiation. Disinfected wastes still require disposal as special wastes and may have their own disadvantages that may preclude their use in many settings.



(Source: WHO)

Example of small landfill pit for health care waste

Incineration of medical waste should only be used as an appropriate option for disposal, for a very small part of the medical waste stream. This may include pathogenic wastes (e.g. body parts); certain expired pharmaceutical wastes; and some special wastes (such as chemotherapy waste—not usually a problem in developing countries). Other sound technologies for waste treatment should be considered for anything that is not potentially infectious (i.e. over 90% of the medical waste). Incinerated medical waste can cause significant negative environmental impacts—mainly from extremely toxic dioxins (and furans) produced during combustion of chlorinated plastics (e.g. polyvinyl chloride or PVC). Dioxins are found in the fly ash, bottom ash and air emissions from the burned plastics (WHO by De Monfort University, UK). Incineration is expensive to set up and requires technical input to operate and maintain. An incinerator needs to be set up and operated by suitable skilled staff. Ash residues from the incinerator will still contain sharps (needles and scalpels) and dioxins and therefore should still be disposed of as special wastes within the landfill.

Proper final disposal. Where none of the above practices are possible, due to lack of funding or organisational structure, suitable final disposal is the only way to deal with medical wastes. For disposal within landfills or dumps, the special waste should be placed in a designated cell or area under close supervision and covered with a layer of lime and at least 50cm of soil. If this is not possible, the special waste should have at least 1m of normal waste immediately placed over and 2m to each side of it.

Training of all employees is very important to ensure that they understand all the risks involved and the necessary precautions. They also need to be trained to understand the system that has been developed so that they can adequately maintain and improve it.

Public Education and Awareness is necessary so that the public can understand the risks associated with medical waste and also understand the systems implemented at the various health facilities.

3.3 Household and Agricultural Hazardous Waste

Hazardous wastes make up only a small percentage of the total household waste stream, however the effect of these hazardous wastes in terms of human health and environmental degradation can be far more significant. Hazardous wastes from agricultural practices are similar to household wastes in that they are usually diverse in nature and most often exist in small quantities. Examples of both these wastes include left over oil and lead-based paints, solvents, paint thinner, wood preservatives, herbicides, pesticides, cleaners, used motor oil, antifreeze and batteries.

There are two opposing views as to what is best practice for dealing with such wastes. The first view is to encourage separation of these wastes from other non-hazardous wastes prior to disposal so they can be dealt with as necessary. This is common in industrialised countries where technologies and finance for safe recycling, or disposal are available. Encapsulation/entrapment should be done where segregation is possible, however the experience in the Caribbean has been that these wastes are integrated with regular municipal waste. This is seen as preferable to collecting the hazardous wastes together into a single, highly concentrated storage area. In many cases, where there are no alternative methods of dealing with separated hazardous wastes, this may be the most 'sound' approach.

The following are sound practices for management of hazardous household wastes:

- Separation of hazardous wastes should be prioritised according to the level of damage each type of waste does, when released into the environment through the disposal method that is used. For example, batteries cause significant problems when incinerated, therefore they should be separated if the waste stream is incinerated.
- There should be ample clear public training as to the need for separation and how and where this can be done.
- Separation, recycling and collection opportunities should be convenient and frequent
- Hazardous goods should be clearly identified as such at the point of purchase, and on labelling, with instructions for special disposal.

- An emphasis should be placed on point-of-purchase take-back systems for substances which can be collected in this manner such as medicines, used oil and batteries.

- Waste exchange programmes where one industry's waste becomes another industry's raw material/resource

- Legislation and policy should be put in place to eliminate the import of hazardous goods where non-hazardous alternatives are available.

- Personnel handling household hazardous goods must receive training to reduce health and safety risks and ensure appropriate disposal.

Where resources or options are available for appropriate disposal of specific hazardous wastes, separation of these wastes is appropriate, however, if separation will result in large quantities of poorly controlled concentrated wastes, it may be better to leave these wastes to be disposed of with normal waste.

3.4 Waste Oil

Used oils often end up in the sewer system, or are disposed of with other solid wastes, where they ultimately end up causing environmental damage.

Apart from used oil from automobiles, electricity generators, the oil and gas sector, petrochemical and other chemical industries, ship and vessels produce considerable waste oil. For example, Bermuda collects and exports 60,000 gallons of waste oil per year for recycling.

Another significant source of used oil is from electricity transformers. This oil has been reported to contain PCB's.

The following sound practices are recommended for handling used oil:

- Oil providers, such as garages and shops, should be required to have storage drums where used oil can be returned free of charge for collection and appropriate reuse or disposal.

- Re-refining into lubricating oil. This is done in Trinidad and includes oils from Shell Antilles and Guyana and Suriname. The residue resulting from re-refining should be disposed of appropriately by bio-remediation (most cost effective), burning within a cement kiln, or within a permanently sealed container in a landfill (least desirable).

- Use as a fuel in an incinerator or electricity generator or heater. In this case, there is a risk that heavy metals contained in the oil may be emitted into the environment. The soundest option for burning of used oil is in a cement kiln where metals are absorbed into the cement matrix.

- Bio-remediation/landfarming as done in Trinidad and Antigua. Where post-treatment heavy metal contamination exists, further treatment is required.

3.5 Batteries

Old flat lead batteries from cars, trucks and other uses contain acid and lead, both of which are hazardous. The following are sound practices for these batteries:

- Drainage of acid with subsequent neutralisation and appropriate treatment and disposal of resulting sludge,

- Export of batteries for re-cycling (storage area required).

- Recycling in controlled environments. Small scale uncontrolled recycling can often be highly polluting and hazardous.

Melting of the lead at a non-ferrous foundry for reuse as sinkers is a common practice. This can be considered as "unsound" and dangerous due to the production of hazardous fumes.

Many batteries contain nickel, cadmium and lithium. These batteries should also be collected separately from other waste and exported to suitable offshore countries for disposal. Provision of storage is necessary to contain these batteries prior to exporting.

3.6 Asbestos

Asbestos (which is a carcinogenic material) should be double wrapped in plastic bags (polyethylene) and buried sufficiently deep in the landfill such that it will not be uncovered. Wetting of the asbestos prior to handling will help suppress the harmful fibres and dust. Breathing apparatus and protective clothing should be used when handling asbestos. The site from which asbestos is being removed should be secured against trespassers. The interior of the building from which asbestos was removed should be cleaned by a wet process, such as wet vacuum, after demolition.

3.7 Human Excreta, Sewage Sludge, Septage and Slaughterhouse Waste

These wastes can contain large levels of pathogens and chemical contaminants at concentrations which are hazardous to human health and the environment. However, these wastes do contain significant nutrients, food value and biomass, which if handled correctly may be beneficial and profitable as fertilisers, compost, animal feed and glue.

The following are sound practices for reducing and handling sewage sludge, septage and slaughterhouse waste.

- Preventing large volumes of sludge. Through separation of sewage and stormwater drainage systems.
- Minimise reliance on centralised sewage system by installation of onsite treatment, and separation of household washwater for reuse
- Land application: Requires regular monitoring of the sludge to show that the metal content is very low.
- Treatment such as drying, liming and composting, or co-composting with yard waste followed by land application. Again, levels of metal contaminants need to be monitored.
- Drying and disposal on landfills. It is important that it is dried to avoid generation of large quantities of leachate.
- Retention Lagoon System for Septage (discussed further under wastewater sections).

3.8 Industrial Waste

Industrial wastes may be divided into a number of categories based on their chemical constituents. By nature, all industrial wastes are hazardous requiring special handling and disposal procedures. With the exception of Trinidad (whose petroleum and heavy industrial sectors present unique and difficult waste management challenges) the countries of the Caribbean are primarily agricultural, tourism and light manufacturing economies. Industrial wastes generated in these Caribbean countries are restricted to small quantities of waste oils from vehicle service stations and power generating facilities, agricultural wastes from pesticide use, organic and inorganic sludges from metal fabrication and electroplating factories and biologically active wastes from food processing and beverage manufacturing plants.

Industrial wastes or industrial residuals may be defined as any wastes which pose unacceptable levels of risk to human health and/or the environment by nature of their toxicity, flammability or corrosivity. These wastes may be either solid or liquid or may be in the form of sludge and by the nature of their organic or inorganic constituents, effect a significant change in cellular or metabolic process at low levels of exposure. Handling (collection and transport) and disposal procedures applied to this category of waste must be based on whether the particular industrial residual may be reused, reprocessed, used as a feedstock in a different industrial process or recycled. In all instances, the final disposal strategy for industrial residuals should be based on: (i) a reduction of the hazardous components of the waste and the safe use or storage of the resultant residue, (ii) the irreversible entrapment of the hazardous components of the waste in an inert medium, or (iii) the total destruction of the waste into its elemental form.

Table 5 provides some information on current industrial waste treatment and disposal options in use in the Caribbean. Further information on the treatment technologies named in the table may be found in the following reference: Treatment Technologies. 2nd Edition. United States Environmental Protection Agency – Office of Solid Wastes. Government Institutes Inc. 1991 or on the website of the Office of Solid Waste of the US Environmental Protection Agency.

Table 5: Industrial Waste Treatment and Disposal Options

Waste Source by Industry	Waste Material	Best Demonstrated Treatment Technologies	Where Successfully Used
Oil and Gas Exploration and Production	Down-hole treatment chemicals and storage containers	Incineration or Bioremediation of chemical residues; Smelting or crushing of steel drums	Trinidad; Outside Caribbean SIDS
	Oily Sludges	Oil recovery; Incineration or Bioremediation	Trinidad; Outside Caribbean SIDS
	Geological Formation Water (Produced Water)	Oil recovery via gravity separation; Chemical constituent removal via reverse osmosis or chemical fixation on suitable adsorbent; Down-hole Injection	Trinidad; Outside Caribbean SIDS
	Drilling Muds and Fluids	Bioremediation if Oil based; Secure burial in Sanitary landfill if water-based; Used as common fill material for industrial sites if new formulation water based muds are used.	Trinidad; Outside Caribbean SIDS
Petroleum Refining	Tank Bottoms (Oily Sludges)	Bioremediation if unleaded; Chemical Fixation if leaded	Trinidad; Outside Caribbean SIDS
	Asphaltic and Bituminous Residues	Recycled as Road Paving Material	Trinidad; Outside Caribbean SIDS
	Oily Wastewater	Oil recovery; Chemical treatment; Biological treatment	Trinidad; Outside Caribbean SIDS
	Treatment Chemicals and Storage Containers	Incineration or Bioremediation of Chemical Residues; Crushing or Smelting of steel containers	Trinidad; Outside Caribbean SIDS
	Sulphurous Gases	Sulphur Recovery	Trinidad; Outside Caribbean SIDS
	Spent Catalysts	Recharge of Catalyst; Recovery of Precious Metals; Secure burial in Sanitary Landfill	Trinidad; Outside Caribbean SIDS
Petrochemicals	Spent Catalysts	Precious Metal Recovery	Outside Caribbean SIDS
	Cooling Water	Heat Recovery Units	
	Organic Sludges	Chemical Oxidation and stabilisation	
	Inorganic Sludges	Chemical Encapsulation	

Continued…

Table 5: Industrial Waste Treatment and Disposal Options (continued from previous page)

Waste Source by Industry	Waste Material	Best Demonstrated Treatment Technologies	Where Successfully Used
Quarry Industry	Silts and Quarry Fines	Common Fill	All Caribbean SIDS
	Overburden	Common Fill	
	Fuels and Chemicals and Storage Containers	Incineration or Secure Burial in Sanitary Landfill	Trinidad
Metal Smelting and Fabrication	Slag	Chemical Encapsulation	Outside Caribbean SIDS
	Cleaning Chemical Waste	Incineration or Chemical Encapsulation	
	Sheet Metal Scraps	Smelting	
Electroplating Industry	Spent Anode and/or Cathode rods;	Secure Burial in Sanitary Landfill or Recycled in Metal Recovery Plant	Outside Caribbean SIDS
	Electroplating sludges	Chemical Stabilisation and Solidification	
Wood Preserving Industry	Organic Sludges;	Chemical Oxidation and stabilisation	Outside Caribbean SIDS
	Metal wastes	Smelting	
Paint and Coatings Industry	Organic sludges	Chemical Oxidation and stabilisation	Outside Caribbean SIDS
	Inorganic sludges	Stabilisation and Solidification	
	Waste Solvents	Incineration	
Cement Industry	Klinker, Limestone and Cement Dust	Neutralisation and Solidification	Trinidad; Outside Caribbean SIDS
Fermented Beverages Industry	Mixed sludge waste	Bioremediation	Trinidad; Outside Caribbean SIDS
Rum Distilleries	Biologically Active Sludges	Bioremediation	Trinidad;
	Mixed wet wastes	Incineration	Outside Caribbean SIDS
Power Generation	Oily Sludges;	Incineration, or Bioremediation	Trinidad;
	Waste Oils;	Incineration, re-refining or Bioremediation	Outside Caribbean SIDS
	Oily rags	Incineration	
Sugar Manufacturing	Bagasse	Used as Fuel for running Boilers	All Caribbean SIDS
	Fly Ash	Chemical Fixation	Outside Caribbean SIDS

4.0 WASTEWATER TECHNOLOGIES

4.1 Introduction

There are numerous technologies to deal with the disposal of wastewater throughout the world. Many of these technologies have been used in the Caribbean but, for many reasons have failed including: inappropriate technology, insufficient operation and maintenance practices, lack of funding and lack of skilled personnel, to name a few. This section will focus on proven sound environmental technologies plus those currently used in the Caribbean, grouped under the following headings.

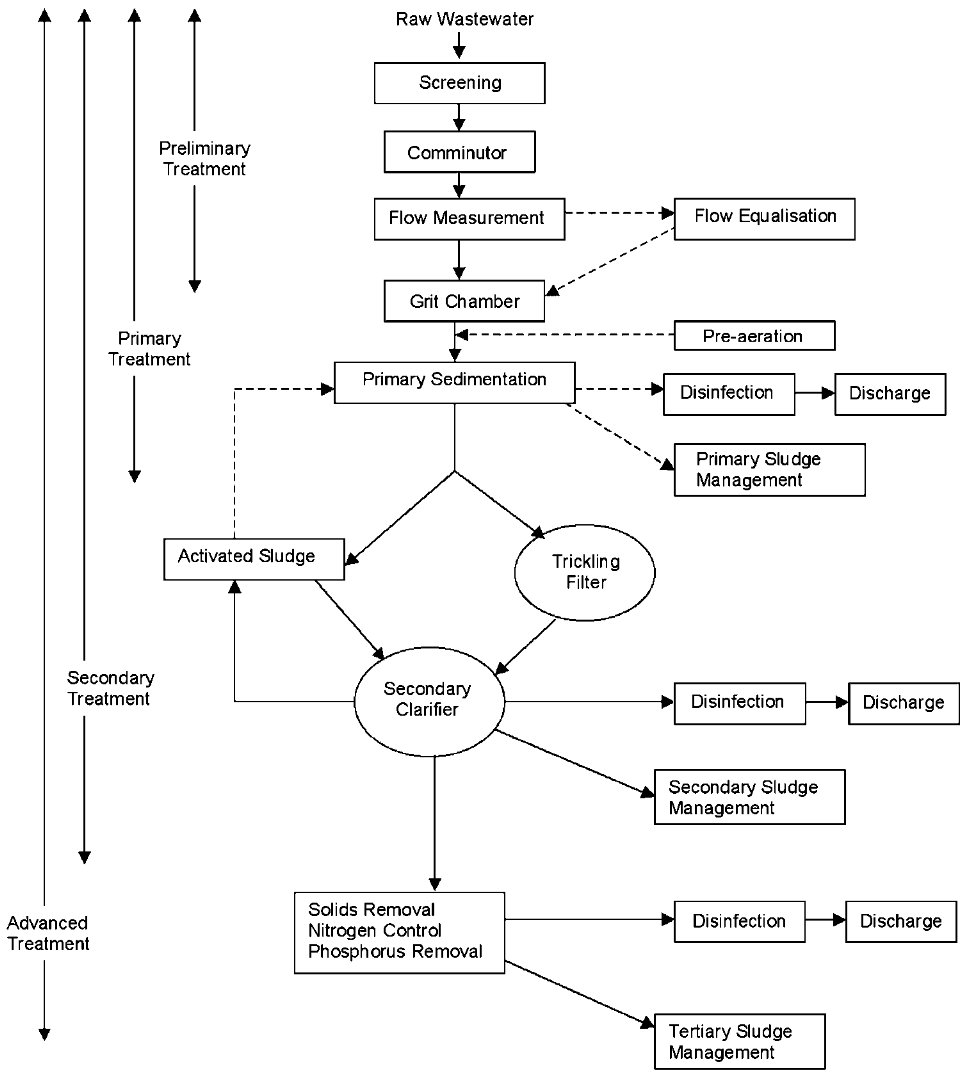
- Wastewater Collection and Transfer
- Wastewater Treatment (On-site)
- Wastewater Treatment (Centralised and Decentralised)
- Wastewater Reuse
- Wastewater Disposal Systems
- Residuals Management
- “Zero” Discharge

Suitable wastewater treatment and disposal technologies are already well documented and much of the following information has been taken from existing reputable sources, again focusing on Caribbean SIDS.

See http://www.cep.unep.org/pubs/techreports/tr40en/index.html for technologies for sewage disposal in the Caribbean SIDS area.

The following diagram illustrates a complete wastewater system. Most of the technologies referred to in the diagram will be further detailed.

WASTEWATER SYSTEM



4.2 Wastewater Collection and Transfer

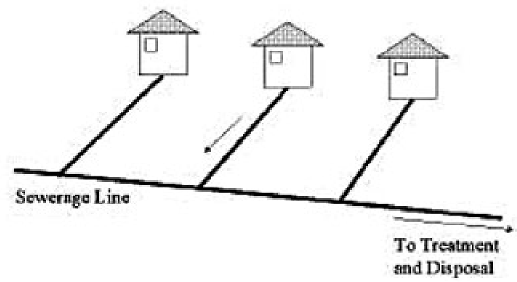
Waste collection and transfer for many on-site disposal methods is simply a "direct drop" into a latrine pit or vault without using water for flushing. Septic tanks require some pipe work to receive waste as well as a water supply, when cistern or pour flush toilets are used. Good plumbing standards are important to ensure proper operation and no leaking pipes. Governments should ensure that plumbing standards are in place and enforced, normally through local building codes and permits that are required prior to the construction of a dwelling.

Many on-site disposal systems require water to transfer waste throughout the treatment system. Thus the availability of a reliable water supply is a major criterion in selecting the type of wastewater disposal method to be used.

Centralised and decentralised systems require reliable water supplies as well as reticulation networks to collect and convey to treatment plants and final disposal locations. These systems often require extensive pumping to transfer wastewater through the reticulation network. Again good plumbing standards are required within dwellings as well as good design criteria and construction practices for reticulation networks and pump stations to minimise potential operation and maintenance problems.

4.2.1 Collection and Transfer Systems

Conventional Sewerage



Source: T. Loetscher (1998)

Technology Description:
Domestic sewage is collected by an underground pipe system to treatment facilities.

Conventional sewerage consists of individual connections (households, commercial enterprises etc.) to a piped reticulation system. The reticulation systems normally include a series of pump stations to convey the sewage through the system, especially on atoll and coastal communities due to flat topography and high groundwater levels. Manholes and other access chambers are required to maintain and clean reticulation systems. Grinder pumps may be installed at individual properties under circumstances where the sewage has to be lifted from the property to the main sewer line.
Systems are normally based on conservative design criteria resulting in high capital construction and operational costs.

Extent of Use:
Major population centres in the Caribbean Region.

Operation and Maintenance:
- High degree of operation and maintenance if pumping is required
- Skilled personnel required

Advantages:
- Minimal intervention by users
- Low to moderate O&M costs
- Promotes good hygiene practices.

Disadvantages /constraints:
- High capital costs
- Technology requiring skilled engineers, contractors and operators.
- Ample and reliable piped water supply required.
- Adequate treatment and/or disposal required for a large point source discharge.

Relative Cost:
- High capital costs

Cultural Acceptability:
- Is generally accepted within the Caribbean Region

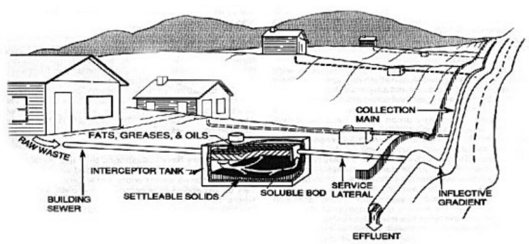
Energy use:
- Low to moderate

Pollution reduction:
- None

Suitability
- High population density

Collection and Transfer Systems:

Small bore (Settled) Sewerage



Source: Daniel and Daniel Engineering Inc.

Technology Description:

Similar to "conventional sewerage" systems where domestic sewage is collected by an underground pipe system and conveyed to treatment facilities. However before the sewage enters the reticulation system, it enters a septic tank, where most settleable solids are removed, thus only the liquid effluent is reticulated. Periodic removal (3-5 years), treatment and disposal of septage are required. Good practices suggest inspection every two years.

The resulting effluent is of "better" quality than if the septic tanks were not in place. However the septic tanks will require maintenance and cleaning.

In principle, the design of the "settled" system is the same as "conventional" systems, however with solids removed from the system, pipelines may be smaller.

Extent of Use:

Increasing use in the Caribbean Region (for example, Grenada)

Operation and Maintenance:

- High degree of operation and maintenance if pumping is required
- Skilled personnel required
- Maintenance and cleaning of septic tanks required

Advantages:

- Promotes good hygiene practices.
- Minimal intervention by users
- Low capital costs
- Moderate O&M costs
- Promotes good hygiene practices.

Disadvantages /constraints:

- Relies on maintenance of individual septic tanks
- Technology requiring skilled engineers, contractors and operators
- Ample and reliable piped water supply required
- Adequate treatment and/or disposal required for a large point source discharge.

Relative Cost:

- Lower capital costs than conventional sewerage

Cultural Acceptability:

- Growing acceptance within the Caribbean Region

Energy use:

- Low to moderate

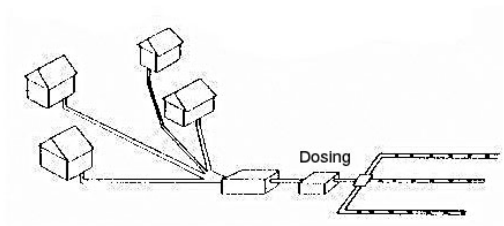
Pollution reduction:

- 30-40% reduction in BOD and suspended solids

Suitability:

- Small communities (for example, housing schemes and villas)

Collection and Transfer Systems:
Cluster Systems



Source: T. Loetscher (1998)

Technology Description:
A cluster system refers to a common collection and disposal system grouping several houses or commercial properties. A cluster system is used to collect sewage from areas with significantly varying housing densities. For example, if there are several villages along a stretch of coastline but very little housing in between the villages, rather than sewer the entire coastline, it may be more economical to develop a cluster system for each village.

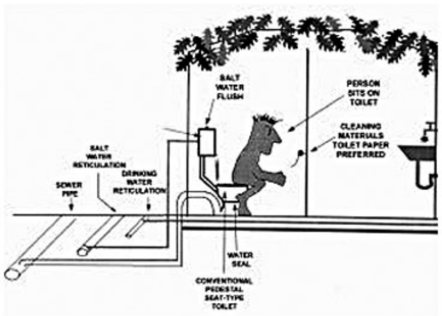
Extent of Use:
Used in the Caribbean

Operation and Maintenance:
- Relatively low especially if gravity sewers are used.

Advantages:	Disadvantages /constraints:
• Less costly than conventional sewerage	• More than one collection, treatment and disposal system
Relative Cost:	**Cultural Acceptability:**
• Moderate	• Accepted within the Caribbean Region

Suitability:
- Suitable for areas requiring sewers but with widely varying housing densities.

Collection and Transfer Systems:
Dual Distribution (Reticulation) Systems



Source: Asian Development Bank

Technology Description:

Dual distribution systems involve the use of water from two different sources and reticulated in two separated distribution networks. Potable water is distributed in one system for most domestic and commercial uses while a second system reticulates non-potable water (i.e. salt, brackish, rain water or treated wastewater) for flushing toilets and other non-potable uses. Using this technology conserves limited freshwater resources. This type of technology would generally be used near the coast where seawater or brackish water is abundant. Saltwater systems require special consideration for the selection of materials due to corrosive nature of seawater. Pipes need to be colour-coded or have other identification to distinguish from potable supply reticulation pipes and to avoid possible cross connections.

Extent of Use:

In the Caribbean, U.S. Virgin Islands, Turks and Caicos, Cayman Islands and the Bahamas use these systems.

Operation and Maintenance:

- High degree of operation and maintenance
- Potential corrosion problems exist that may compound maintenance requirements.

Advantages:

- Use of lesser quality waters for non-potable purposes reduces the use of limited freshwater resources.

Disadvantages /constraints:

- High capital costs
- Technology requiring skilled expertise such as engineers, technicians, contractors and operators.
- Risk of polluting groundwater through leaks
- Risk of cross connections

Relative Cost:

- High due to the duplication of distributions networks and the need to use corrosion resistant materials if seawater is used.

Cultural Acceptability:

- Growing acceptance in water-scarce

Energy use:

- Moderate to high

Pollution reduction:

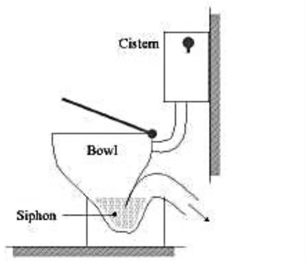
- Water conservation will result in pollution reduction over the life-cycle of the system

Suitability:

- In water-stressed areas

Collection and Transfer Systems:

Cistern-Flush Toilet



Source: T. Loetscher (1998)

Technology Description:

The toilet bowl consists of a siphon, which provides a water seal against bad odours from the effluent pipe. Excreta are flushed away with water stored in the cistern (depending on the type between five to twenty litres per flush).

Cistern-flush toilets provide the highest level of convenience and have a very clean and hygienic appearance. The cistern-flush toilet itself has no treatment effects.

Cistern-flush toilets use large amounts of water. Installing them results in a water use of around 15 litres per flush. Dual flush toilets are available to reduce water used to flush urine. Increasingly, low flush toilets are being used with reduced water consumption to approx. 10 litres per flush. Cistern-flush toilets are more prone to malfunctioning and leakage than pour-flush toilets.

Extent of Use:

Extensively throughout the Caribbean

Operation and Maintenance:

- Subject to malfunction of flushing system.

Advantages:

- Easy to use and clean
- Hygienic

Disadvantages /constraints:

- High water use

Relative Cost:

- Higher than pit latrines and pour flush

Cultural Acceptability:

- No cultural problems

Energy use:

- NA

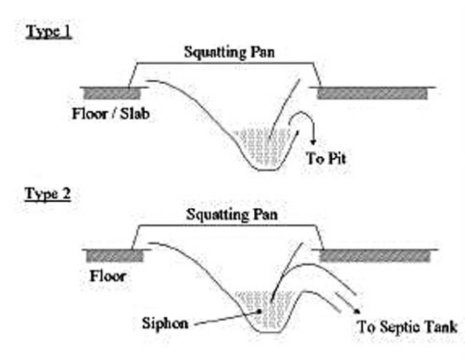
Pollution reduction:

- NA

Suitability:

- Very suitable if reliable water supply exists and if the user can afford it.

Collection and Transfer Systems:
Pour-Flush Toilet



Source: T. Loetscher (1998)

Technology Description:
The toilet pan consists of a siphon, which provides a water seal against bad odours from the effluent pipe. Excreta are flushed away with water, which is poured manually into the pan by using a scoop. The amount of water required to flush this type of toilet is between two and three litres. Pour-flush toilets provide a high level of convenience and have a very clean and hygienic appearance. The pour-flush toilet itself has no treatment effects. The pour flush toilet can also be constructed with a riser to sit on instead of the squat type as shown.

Extent of Use:
Limited use in the Caribbean region

Operation and Maintenance:
- Easy to operate and maintain

Advantages:
- Easy to use and clean
- Hygienic if riser is used
- Uses less water then cistern-flush toilets

Disadvantages /constraints:
- Requires storage and handling of water

Relative Cost:
- Lower than cistern flush

Cultural Acceptability:
- Not widely accepted

Energy use:
- NA

Pollution control:
- NA

Suitability:
- Very suitable in areas with limited piped water supply.

4.2.2 On-Site Wastewater Systems

Ecological Sanitation

Double Vault urine diverting dry eco-toilet

Source: www.ecosanres.org

Technology Description:

Ecological sanitation systems are designed around true containment and provide two ways to render human excreta innocuous: dehydration and decomposition. The preferred method will depend on climate, groundwater tables, amount of space and intended purpose for the sanitised excreta. Dehydration is the chemical process of destroying pathogens by eliminating moisture from the immediate (containing) environment. Some drying materials, like wood ash, lime and soil are added to cover the fresh deposit. Ash and lime increase pH, which acts as an additional toxic factor to pathogens if the pH can be raised to over 9.5. The less moisture the better and in most climates it is better to divert the urine and treat it separately. Urine is never mixed in this toilet but continuously diverted into a separate container and later used in diluted form as plant fertiliser

Extent of Use:

Not widely used in the Caribbean

Operation and Maintenance:

- Requires care in operation; easy to maintain

Advantages:

- Systems do not require water for flushing, reduces domestic water consumption.
- Reduces the quantity and strength of wastewater to be disposed of on-site.
- Suited for new construction at remote sites where conventional on-site systems are not feasible.
- Self-contained systems eliminate the need for transportation of wastes for treatment/disposal.
- Diverts nutrient- and pathogen-containing effluent from soil, surface water and groundwater.

Disadvantages /constraints:

- Maintenance of these toilet systems requires more responsibility by users than conventional wastewater systems.
- Removing the finished end-product is an unpleasant job if the toilet system is not properly installed or maintained and may produce odours.
- Smaller units may have limited capacity for accepting peak loads.
- Using an inadequately treated end product as a soil conditioner may have possible health consequences.

Relative Cost:

- Low

Cultural Acceptability:

- Not widely used

Energy use:

- Low

Pollution reduction:

- Waterless system greatly reduces pollution

Suitability :

- Well suited to the region especially in areas where water is not readily available

On-Site Wastewater Treatment
Portable Chemical Toilets

Source: CEHI

Technology Description:
Portable toilets are self contained structures brought to a site to provide sanitary facilities. They are often used at many events where large numbers of people congregate. The toilet unit is a small toilet room built over a watertight waste holding tank. The service truck has a pump and a large tank which is divided into two compartments, one for fresh charge for use in cleaning the units and the other for receiving and transporting the effluent for proper disposal

Extent of Use:
Widely used throughout the Caribbean

Operation and Maintenance:
- Easy to use, requires frequent servicing and disinfection

Advantages:
- Requires minimal space.
- Low cost.
- Simplicity.
- Reliability.
- Can be emptied via suction wand at a pumpout facility or at a dump station designed especially to receive portable toilet waste.

Disadvantages /constraints:
- Needs to be serviced regularly to avoid health hazards
- Limited capacity

Relative Cost:
- Low

Cultural Acceptability:
- Acceptable

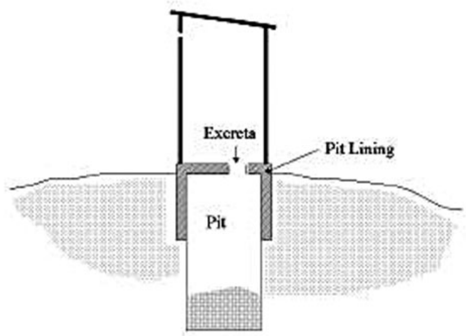
Energy use:
- Low

Pollution reduction:
- NA

Suitability :
- Suitable for areas where there is no centralised system; construction sites, parties

On-Site Wastewater Treatment

Pit Latrine



Source: T. Loetscher (1998)

Technology Description:

The pit latrine is designed for the on-site disposal of human excreta. It consists of a concrete squatting plate or riser, which is placed over an earthen pit. Its design life is between 15 - 30 years. If less than 10 years, a double vault composting (DVC) latrine should be considered instead. The pit diameter is between 1 - 1.5 m. The depth of the pit is at least 2 m, but usually more than 3 m. The top 0.5 m of the pit always requires lining. In loose soil, the entire pit should be lined in order to prevent collapse. One unit can serve one or several households.

If constructed properly, they provide good health benefits. All types of anal cleansing materials may be used. Since ventilation of pit latrines is simple, odours and insect nuisance may occur. Excreta can be seen through the hole in the squatting plate.

Extent of Use:

Used throughout the Caribbean Region especially in rural areas

Operation and Maintenance:

- Easy to operate and maintain

Advantages:

- Low cost
- Encourages public involvement in construction (potential for self help is high)
- Pit latrines do not need water for flushing
- Simple to construct
- Limited land area required
- Can be used in areas with low permeability soils

Disadvantages /constraints:

- Since pit latrines involve soil absorption, there is a danger of groundwater contamination
- Odours and insect nuisance may occur
- Usually removed from main dwelling

Relative Cost:

- Lowest cost for on-site technologies

Cultural Acceptability:

- Culturally accepted in much of the Caribbean

Energy use:

- NA

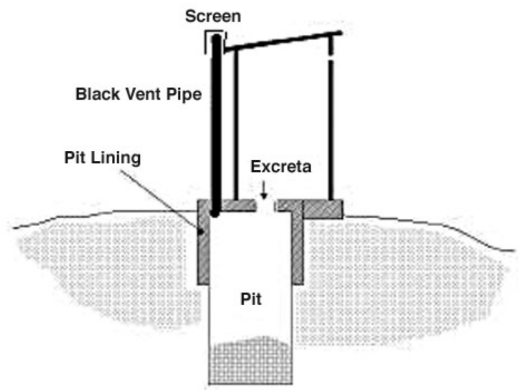
Pollution reduction:

- NA

Suitability :

- Suitable low cost waste disposal method

On-Site Wastewater Treatment
VIP Latrine



VIP latrine, showing black pipe & screen (modified by CEHI)

Technology Description:

The ventilated improved pit (VIP) latrine is designed for the on-site disposal of human excreta. With the exception of some enhancements in design (e.g. a dark, vent pipe, to encourage upflow of air and improve ventilation; screening the top of the ventilation pipe which assists in reducing flies) its construction is similar to that of the pit latrine.

VIP latrines do not need water for flushing. They rely on soil absorption and are simple to construct. If constructed properly, they provide good health benefits.

All types of anal cleansing materials may be used.

A VIP latrine can be upgraded to a latrine with vault or a pour-flush latrine.

Extent of Use:

Being actively promoted as an improvement on the pit latrine with increasing use in the Caribbean.

Operation and Maintenance:

- Easy to operate and maintain

Advantages:

- Low cost
- Encourages public involvement in construction (potential for self help is high)
- Pit latrines do not need water for flushing
- Simple to construct
- Limited land area required
- Can be used in areas with low permeability soils
- The ventilation of VIP latrines is good, odours and insect nuisance normally do not occur.

Disadvantages /constraints:

- Since pit latrines involve soil absorption, there is a danger of groundwater contamination
- Odours and insect nuisance may occur
- Usually removed from dwelling

Relative Cost:

- Slightly higher than pit latrines

Cultural Acceptability:

- Culturally accepted in much of the Caribbean but being phased out in some islands (for example in Barbados)

Energy use:

- NA

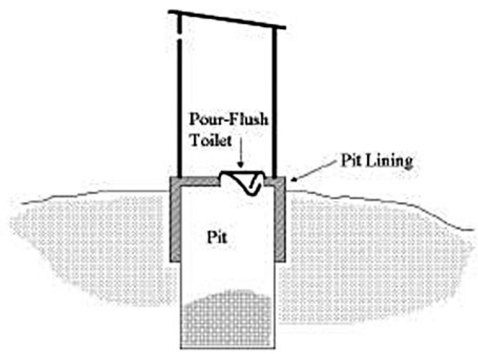
Pollution reduction:

- NA

Suitability:

- Suitable low cost waste disposal method however not suitable for flood prone areas

On-Site Wastewater Treatment
Pour-Flush Latrine



Source: T. Loetscher (1998)

Technology Description:
The pour-flush latrine is designed for the on-site disposal of human excreta. Its construction is similar to that of the pit latrine, except that it uses a pour-flush pan instead of a squatting plate with a hole in it. One unit can serve one or several households.

If constructed properly, they provide good health benefits.

The water seal in the pour-flush pan forms an effective barrier against odours and insect nuisance and prevents excreta from being seen once flushed.

Extent of Use:
Not commonly used throughout the Caribbean Region

Operation and Maintenance:
- Easy to operate and maintain

Advantages:
- Pour-flush latrines need small amounts of water for flushing.
- They are simple to construct, thus the potential for self help is high

Disadvantages /constraints
(as other pit latrine technologies):
- Since pit latrines involve soil absorption, there is a danger of groundwater contamination.

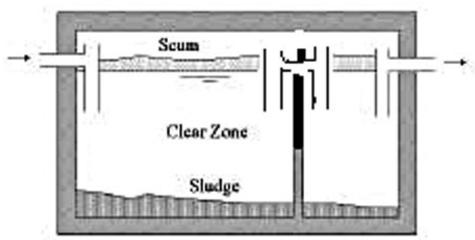
Relative Cost:
- Low

Cultural Acceptability:
- Culturally accepted

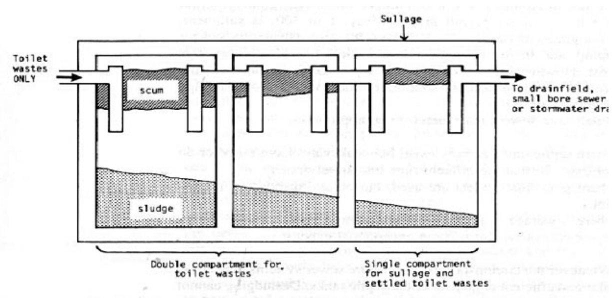
Suitability:
- Suitable for household use, however contamination of groundwater may be an issue.

On-Site Wastewater Treatment

Septic Tank



Standard septic tank with baffles (Source:CEHI)



Three chamber septic tank Source: Kalbermatten et al. (1982)

Technology Description:

The septic tank is designed for the on-site treatment of domestic sewage. The tank is usually located underground and usually consists of two compartments allowing for one to three days of hydraulic retention. The first compartment is approximately twice as large as the second one. Baffles should be placed diagonally, to maximise the transit time of sewage between entry and exit from each chamber. Septic tanks can be constructed with only one compartment. However, this will result in significantly reduced treatment effects and cost savings are minimal.

There are two main treatment effects:

1) Contaminants are removed from the sewage by either settling of heavy particles or by flotation of materials less dense than water (e.g. oils and fats). The sludge layer at the bottom of the tank is a result of the settling process. The scum layer is formed through the flotation process.
2) Bacteria digest organic matter in the sludge and the scum layer. The digestion process is important because it prevents the excessive accumulation of sludge.

Septic tanks can reduce the BOD of raw sewage by up to 40% and the suspended solids content by 30-40%. Their effluent is thus more readily absorbed into the ground than raw sewage. Therefore, smaller soil absorption facilities (e.g. seepage pit or drain field) are required.

The effluent of septic tanks is still heavily contaminated with pathogens, organic matter and nutrients that require further treatment. Effluent quality can be further improved by installing a solids filter on the septic tank outlet. This prevents the carry over of solids into the absorption field.

Since they can only accept liquid waste, they must be connected to a flush toilet. Thus they are not suitable where water supply is scarce or unreliable.

Extent of Use: Extensively used in the Caribbean

Operation and Maintenance:

- Septic tanks require routine checks for sludge and scum levels every two years. Properly designed and constructed septic tanks require desludging every three to five years. (Note: During the desludging process, some sludge should be left to restart the biological process. Tanks should be refilled.)

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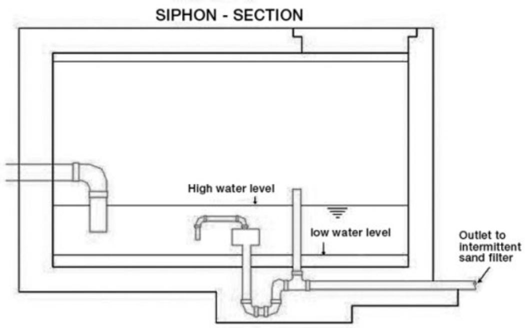
Advantages: • Greywater can be treated together with toilet waste • Easy to construct • Use of a variety of construction materials (in some cases prefabricated)	**Disadvantages /constraints:** • Construction of septic tanks requires skilled labour • Effluent requires further treatment
Relative Cost: • higher than the cost of a pit latrine but relatively low as a percentage of total building construction costs	**Cultural Acceptability:** • Culturally accepted
Energy use: • NA	**Pollution reduction:** • 30-40% reduction in BOD and suspended solids
Suitability: • Suitable for most applications.	

Dosing Devise
Sewage siphon



(Source: Daniel and Daniel Engineering Inc.)

The purpose of a siphon is to secure an intermittent discharge to a sand or other filter, after effluent leaves a septic tank, thus allowing a considerable period of time for one sewage dose to work off in the filters before another flush is received. It also provides distribution over a larger area and in a more even manner than if the sewage was allowed to dribble with an uncontrolled flow.

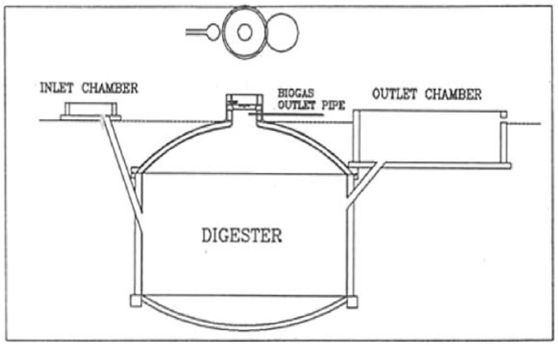
The siphon action is rather simple and requires two conditions for its operation:

- All air must be evacuated from the piping
- The discharge end must be lower than the liquid level in the tank from which the liquid is to be removed

The essential principle of operation is that a column of air is trapped between two columns of water and when the water in the tank rises to a predetermined height (called the discharge line), the pressure forces out the confined air, upsetting the balance and causing a rush of water through to the pipes leading to the distribution field. The entire operation is fully automatic and occurs as a function of the water level in the tank.

Manufacturers of sewage siphons usually furnish full information for their setting and other details. If properly installed and maintained, sewage siphons require very little attention and will flush without failure for many years. However, they are susceptible to stoppage if rags, newspaper and similar solids get into the sewage. If sludge is allowed to build up, it will prevent proper operation until the sludge is removed.

Biodigester
(Biogas – Biofertiliser Plant)



Source: Scientific Research Council, Jamaica (1995)

Technology Description:

The biodigester system is a concrete tank used for the degradation of organic waste such as animal waste, sewage, green plants and plant waste and agro-industrial waste and wastewater to produce biogas and biofertiliser. The technology does not work well with human excreta alone. The system utilises the anaerobic technology (i.e. in the absence of air). When the organic material listed above is placed into the system it remains in the system for about thirty days (the retention time) during which bacteria break it down and produce biofertiliser (digested slurry) and biogas.

The gas is then collected in the dome of the digester and carried through PVC pipelines to different sources of use as stoves, refrigerators and diesel engines, after scrubbing. The digested slurry is stored in the outlet chamber where it can then be trenched/piped to the field or dried and carried to the point of use.

The daily yield of biofertiliser corresponds to the amount of the daily input of fresh material while the daily quantity of gas corresponds to half the digester size. Source: SRC www.jawmanins.com

Extent of Use:

Widely used in the Caribbean (e.g. Jamaica, Guyana, Barbados, Trinidad and Tobago, Grenada)

Operation and Maintenance:

- Low degree of operation and maintenance required (if gravity fed)
- Relatively low skilled personnel required
- Gas must be scrubbed before use

Advantages:

- Prevents pollution of groundwater
- Low potential for malodours
- Sludge can be used as bio-fertiliser
- Effluent utilised as liquid fertiliser
- Improved farm sanitation
  (fly/insect nuisance significantly reduced)

Disadvantages /constraints:

- Skilled labour is required for the construction of a watertight tank

Relative Cost:

- Low capital cost (US$ 100/cubic meter)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within the Caribbean

Energy Usage:

- Generated energy 0.5 m^3 methane/m^3 biodigester volume

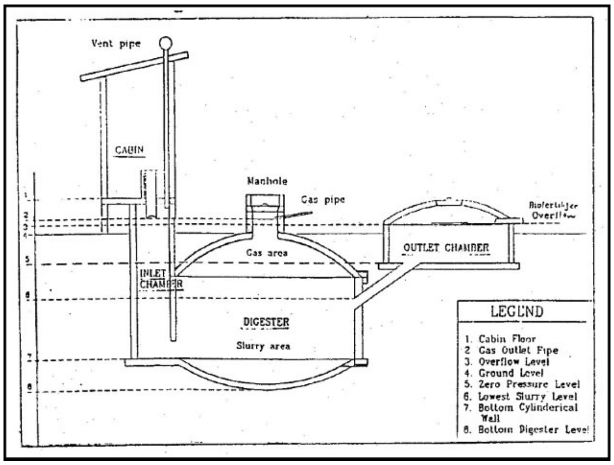
Pollution Reduction:

- 80% BOD and SS removal

Suitability/Appropriateness

- Farms, agro-industrial applications

Sanitary Bio-latrine Unit (SBU)



Source:
Scientific Research Council (SRC), Jamaica (1995) www.jawmanins.com

Technology Description:

The Bio-latrine Units are installations where the Biodigester plants have been built to collect the waste from a VIP latrine. From the cabin the faeces go directly into the inlet chamber and into the digester under gravity. The design and development of the SBU incorporates concepts from both VIP latrines and the agricultural biogas plant.

Within 120 days the bacteria degrades the excreta. The result of this process is biogas, a renewable source of energy. The digested process matter is then discharged automatically to the outlet chamber where it over flows to a tertiary treatment system.

The number of cabins and the size of the digester are determine by the number of persons using the system daily

Extent of Use:

In Jamaica, in camping sites, inner city and rural communities

Operation and Maintenance:

- Low degree of operation and maintenance required
- Relatively low skilled personnel required
- Gas scrubbed before use

Advantages:

- No handling of human excreta
- Fly/insect nuisance significantly reduced
- Prevents underground water pollution
- No malodour
- Aesthetically improvement over VIP latrine
- Promotes good hygiene practices.

Disadvantages /constraints:

- Effluent requires tertiary treatment

Relative Cost:

- Higher capital costs than VIP latrines (US$ 100/cubic metres)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within Jamaica

Energy Usage:

- Generate energy 1 m^3/m^3 sewage

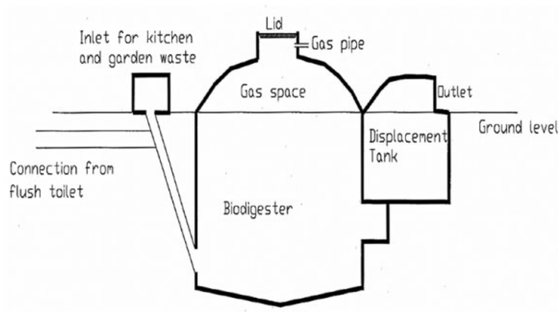
Pollution Reduction:

- > 75% BOD and SS removal

Suitability/Appropriateness

- Single households, institutions, small communities

Biodigester Septic Tank (BST)



Source: Scientific Research Council (SRC), Jamaica (1995)
www.jawmanins.com

Technology Description:

The BST is an on-site sanitation unit, which provides for the disposal of toilet (black) wastewater as well as of kitchen and bathroom (grey) water.

The BST totally relies on the bioorganic breakdown of the organic waste. The biochemical process occurs under airless conditions and produces biogas and the liquid effluent. The sizing of the system is determined by number of persons, wastewater generation rate and retention time (6 days).

Extent of Use:

In Jamaica, in single households, apartment and townhouse complexes

Operation and Maintenance:

- Low degree of operation and maintenance required
- Relatively low skilled personnel required
- Gas scrubbed before use

Advantages:

- No handling of human excreta
- Fly/insect nuisance significantly reduced
- Prevents underground water pollution
- No malodours
- Little or no sludge produced
- Improvement over traditional septic tank (solids treated)

Disadvantages /constraints:

- Effluent requires tertiary treatment

Relative Cost:

- Higher capital costs than traditional septic tanks (US$ 100/cubic metre)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within Jamaica

Energy Usage:

- Generates energy 1 m^3/m^3 sewage

Pollution Reduction:

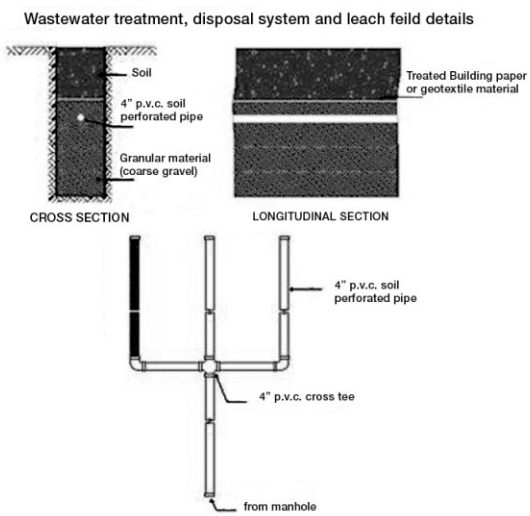
- > 80% BOD and SS removal

Suitability/Appropriateness

- Single households, apartment and townhouse complexes, institutions, small communities

Combined On-Site Wastewater Treatment and Disposal

Drain Field (French drain or tile field)



Source: Daniel & Daniel Engineering, Inc

Technology Description

The septic tank is necessary pre-treatment and is discussed earlier. The drain field is designed for the on-site disposal of sewage. It is an area of land consisting of one or several long trenches, into which sewage is discharged through underground perforated pipes which are surrounded by granular media. Alternatives to perforated pipes that may provide increased infiltration capacity are under development. The sewage percolates into the granular bed after which it is decomposed by bacteria in the soil. A geomembrane is placed above the granular bed that prevents silt from clogging the bed. Usually, one drain field receives the effluent from one septic tank.

Tile fields should be sized to accept grey water. To prevent run-on, the tile field is usually slightly raised. The life of a drainage field can be extended by placing a solids filter on the outlet of the septic tank to prevent solids entering and blinding the drainage field.

Extent of Use:

Low usage because of land availability and seepage pits are easier and cheaper to construct

Operation and Maintenance:

- If constructed properly, no maintenance is required
- O & M reduced if septic tank or other system using trenches are maintained properly
- Area should be grassed and heavy traffic avoided

Advantages:

- The construction of drain fields is simple
- Better disposal method than seepage pits

Disadvantages /constraints:

- Large space requirements.
- Since drain fields are based on soil absorption, there is a danger of groundwater contamination
- Improved effluent quality

Relative Cost:

- Low to moderate as compared to sea outfall

Cultural Acceptability:

- Culturally accepted

Energy use:

- NA

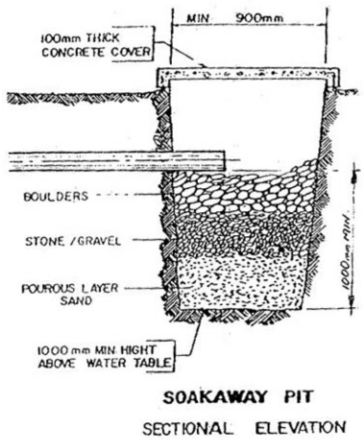
Pollution reduction:

- Further polishing of effluent achieved

Suitability:

- Very suitable to dispose of septic tank effluent where enough space is available and where the soil has medium absorption capacity (not too slow and not too fast resulting in ground water contamination)

Combined On-Site Wastewater Treatment and Disposal
Seepage Pit (Soakaway)



Technology Description:
The seepage pit is designed for the on-site disposal of sewage effluent. It consists of an underground pit, the walls of which are usually stone packed. Through the voids in the packing material, effluent percolates into the soil, where microorganisms decompose the effluent.

Usually, one seepage pit receives the effluent from one septic tank. The soakaway should be sized to accept greywater. Percolation tests should be conducted for appropriate sizing of the pit.

Source: Daniel and Daniel Engineering Inc.

Extent of Use:
Soakaway pits are extensively used in the Caribbean

Operation and Maintenance:
- Minimal maintenance is required.
- O & M reduced if septic tank or other system using trenches are maintained properly

Advantages:
- The construction of a seepage pit is simple

Disadvantages /constraints:
- There is a danger of groundwater contamination

Relative Cost:
- Low compared to tile field

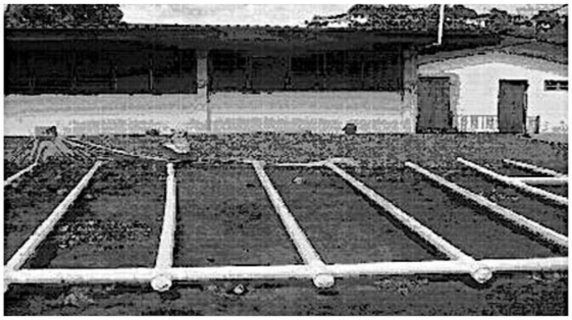
Cultural Acceptability:
- Culturally accepted

Energy use:
- NA

Pollution reduction:
- Further polishing achieved

Suitability:
- Suitable to dispose of septic tank effluent where groundwater table is not high.

Combined On-Site Wastewater Treatment and Disposal
Mound systems (raised bed)



Source: Daniel and Daniel Engineering Inc.

Technology Description:
Mounds are used for those soil and site conditions where conventional disposal trenches are unsuited due to shallow soils overlaying rock, or where water tables are high in permeable soils. The mound provides for distribution of effluent onto a layer of suitable material of sufficient depth (around 600mm) to ensure satisfactory remediation before entering the natural soil and then diffuse into the water table. The mound can be constructed directly on the natural ground surface, which may be ploughed or cultivated beforehand. Wastewater treatment takes place within the fill of the mound, enabling the unit to be placed on freely permeable or slowly permeable sub-soils.

The mound should be sized to accept greywater. Percolation tests should be conducted for appropriate sizing of the mound.

Extent of Use:
Low usage in the Caribbean Region

Operation and Maintenance:
- Minimum maintenance is required
- O & M reduced if septic tank or other system using trenches is maintained properly

Advantages:
- The construction of mounds is simple
- Better disposal method than seepage pits
- Increases the evapo-transpiration rate

Disadvantages /constraints:
- Large space requirements.
- There is a danger of groundwater contamination

Relative Cost:
- Higher cost than a tile field

Cultural Acceptability:
- Culturally accepted

Energy use:
- NA

Pollution reduction:
- Further polishing achieved

Suitability:
- Suitable to dispose of septic tank effluent where groundwater table is not high.

On-Site Wastewater Treatment
Composting Toilets

Construction of composting toilet in Fiji (Courtesy SOPAC).

Technology Description:

Composting is a natural process through which organic material is decomposed and returned to the soil producing a valuable soil conditioner (humus). In a composting toilet, water is not used at all and human waste and other organic materials (carbon source) are deposited into a digestion chamber where aerobic bacteria decompose solid portions and liquids are left to evaporate through a specially designed ventilation system.

Digestion chambers will take a certain period of time to fill up depending on the particular system. Once full the chamber is left to compost over a period of weeks. During this time a second chamber is used. Finished compost can be cautiously removed avoiding contact with hands and can be dug into the garden or trenched around roots of trees.

Extent of Use:

Used to a limited extent in Dominica

Operation and Maintenance:

- Composting toilet systems require bulking material as a carbon source (wood chips, dried leaves, coconut husks, food waste etc.)
- Requires manual removal and disposal of finished composting material after a period of time.

Advantages:

- Low land space requirements
- Low operational and maintenance requirements
- No water required
- Does not pollute groundwater
- Produces valuable soil conditioner

Disadvantages /constraints:

- Compost may still be contaminated if not fully matured
- Manual labour required

Relative cost:

- Higher than traditional latrines

Cultural Acceptability:

- Limited acceptance within the Caribbean region

Energy use:

- NA

Pollution reduction:

- NA

Suitability:

- Suitable for rural and agricultural areas

4.3 Wastewater Treatment (Centralised and Decentralised)

Generally the major difference between centralised and decentralised treatment system technologies is the population that they are designed to service, with centralised systems servicing larger population centres. All of these treatment systems require the use of water throughout the process to flush, convey, treat and dispose of waste and wastewater. Wastewater treatment processes consist of five stages related to the level of treatment that is achieved.

A. The five stages or areas of wastewater treatment are:

i. Preliminary treatment
ii. Primary treatment
iii. Secondary treatment
iv. Tertiary treatment
v. Disinfection

4.3.1 Preliminary Treatment

Preliminary systems are designed to remove or cut up the larger suspended and floating materials. The primary purpose of preliminary treatment is to protect the pumping equipment and the subsequent treatment units. Flow measurement, screening, pumping and girt removal are normally the first steps in processing of municipal wastewater. Chlorine solution or ferric chloride may be added to raw wastewater for odour control and to improve settling characteristics of the solids. The arrangements of the preliminary units vary but the following general rules apply. A flume is typically located first and ahead of screens and prior to the introduction of in-plant recycle flows. Screens protect pumps and prevent large solids from fouling subsequent units. With variable-speed pumps, a magnetic flow meter is installed at the discharge side of the pumps, because the pumping rate is paced to be identical to the influent flow. Grit removal reduces abrasive wear on mechanical equipment and prevents the accumulation of sand in tanks and piping. Although ideally grit should be taken out ahead of the lift pumps, grit chambers located above ground are far more economical and offset the cost of preliminary units.

Grit Chambers (Sand & Grit Removal)

These handle removal of sand and grit particles with particle size > 0.2 mm. Grit storage capacity should be sufficient for a removal frequency of 1 to 2 times every week only. At the bottom of the grit channel a facility is needed to provide adequate grit storage potential.

Grit includes sand and other heavy particulate matter, such as seeds and coffee grounds, which settle from wastewater when the velocity of flow is reduced. If not removed in preliminary treatment, grit in primary settling tanks can cause abnormal abrasive wear on mechanical equipment and sludge pumps, can clog pipes by deposition and can accumulate in sludge holding tanks and digesters. Grit chambers are designed to remove particles equivalent to fine sand, defined as 0.2 mm-diameter particles with a specific gravity of 2.7 and a minimum of organic material included. A variety of systems are employed depending on the quantity of grit in the wastewater, the size of the treatment plant and the expenditures allocated to installation and operation. Standard chambers include channelshaped settling tanks, aerated units with hopper bottoms and forced vortex tanks. Separated grit may be further processed in a screw-type grit washer or cyclone separator.

The earliest grit chambers consisted of two or more long narrow channels constructed in parallel with space for grit storage. A proportional weir placed at the discharge end controlled the flow such that the horizontal velocity was maintained at about 0.3m/sec independent of the quantity of flow. This allowed the grit to settle while providing a scouring velocity to flush through organic suspended solids. Buckets on a continuous chain scraped material from the bottom into a receptacle, thus avoiding hand cleaning.

The most popular type of grit chamber in smaller plants is a hopper-bottomed tank with influent pipe entering on one side and an effluent weir on the opposite. The chamber is small, with a detention time of approximately 1 min. at peak hourly flow and is often mixed by diffused aeration to keep the organics in suspension while grit settles out. Solids are removed from the hopper bottom by an air-lift pump, screw conveyor, or centrifugal pump.

Grit clarifiers, sometimes called detritus tanks, are generally square, with influent and effluent weirs on opposite sides and a centrally driven scraper for removal by a screw auger. The clarifier is a shallow tank with a short detention time or a deeper aerated chamber to improve grit separation while freshening the raw wastewater.

Screening\screens and Bar rack

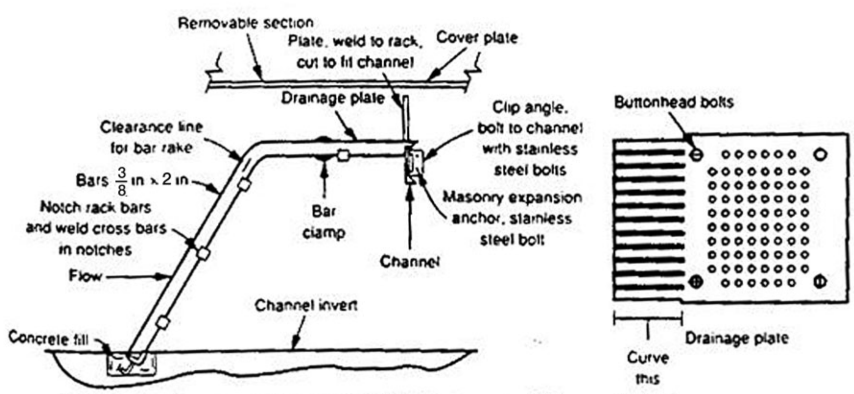
Coarse Screens are classified as either bar racks (trash racks) or bar screens, depending on the spacing between the bars. Bar racks have clear spacing of 5.08 to 10.16 cm (2.0 to 4.0 in) and bar screens typically have clear spacing of 0.64 cm to 5.08 cm (0. 25 to 2.09in)

Screening

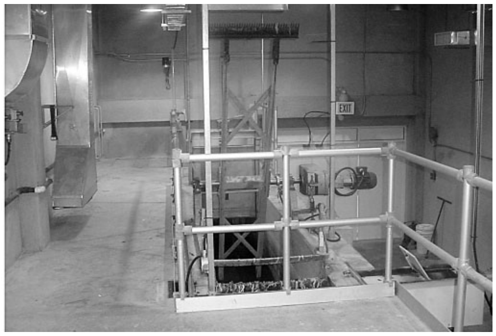
Screening is necessary at the beginning of the treatment plant
- for safety and aesthetic reasons
- to protect pumps, weirs and other machinery
- to prevent clogging of V-notch weirs, pipes, orifices, etc.

They can be manually racked or be cleaned mechanically.

The approach channel flow velocity should be 0.5 to 0.6 m/s to prevent sediment settling.



Lay out of manually cleaned bar screen (9).



Mechanised cleaning of screens,
DOWASCO Wastewater Treatment Plant, Dominica

(Daniel and Daniel Engineering Inc.)

Manually cleaned screens/bar rack
St. George's University Grenada

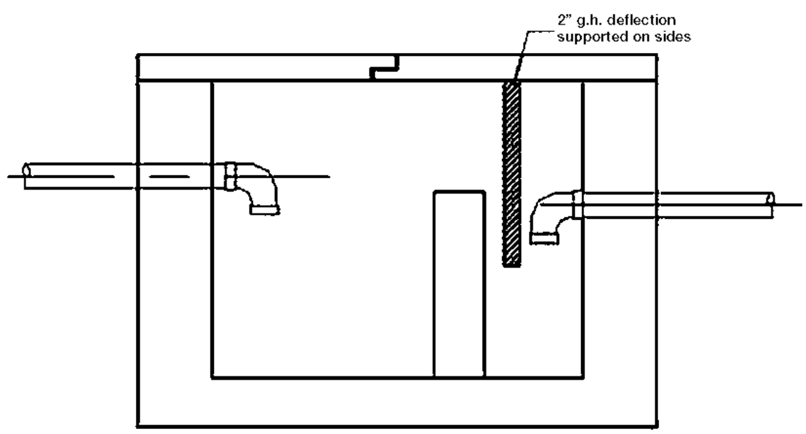
(Daniel and Daniel Engineering Inc.)

Grease traps & Comminutors

Grease traps are designed to separate Fats, Oils and Grease (FOG) from the wastewater before it enters the collection system or septic tank. The design principle is similar to that of septic tanks.

Communitors are devices used to cut up (comminute) solids in wastewater. This may be necessary to improve downstream operations and processes. Often these devices are used to cut up material retained on screens. Comminutors and grinder pumps are used to both grind and lift the wastewater to equalisation or primary settling tanks. In some cases, grinder pumps are installed at low-lying properties to lift the sewage to the collector main.

100 LBs. GREASE TRAP - SECTION



General comments

Some literature distinguishes between preliminary and primary (sedimentation and flotation). Some literature lump all and call them primary treatment.

The literature also includes as pre-treatment of industrial wastewater, the flow equalisation and neutralisation to make wastewater more acceptable for discharge into municipal systems.

4.3.2 Primary treatment

Primary treatment consists in most cases of primary sedimentation. This treatment normally precedes biological treatment and is aimed at removing settleable solids, floating material, oil and grease and reduce the organic load on the subsequent treatment units. Typically when used for municipal wastewater, primary sedimentation can remove 50% of the influent suspended solids and 30% of the influent biochemical oxygen demand.

Primary treatment units include primary clarifiers, Imhoff tanks and any sedimentation basin.

Advanced preliminary treatment involves the use of sand and grit removal and the use of milli-screens (mesh size 2 to 3 mm) and in some cases is the only treatment used prior to disposal by long sea outfall.

4.3.3 Secondary treatment

Secondary treatment is generally biological treatment, which is the nucleus of almost any aerobic or anaerobic treatment process, aimed at removing or stabilising, by means of microorganisms, the colloidal and soluble organic matter present in wastewater. The process requires adequate environmental conditions for the growth of micro-organisms, such as optimum pH, temperature, oxygen or lack of oxygen and nutrients.

There are principally two types of secondary biological treatment, namely:

a. Aerobic treatment – requiring air for the breakdown to take place
b. Anaerobic treatment – the breakdown takes place without air

Facultative treatment is a combination of both aerobic and anaerobic treatment processes.

4.3.4 Tertiary Treatment

Tertiary or advanced treatment includes processes required to remove various contaminants remaining in the effluent after primary and secondary mechanical and biological treatment. Tertiary treatment is the collective name given to those processes that are used to improve the effluent by additional removal of suspended solids and a further reduction in numbers of disease causing faecal coliform.

4.3.5 Disinfection

Primary, secondary and even tertiary treatment cannot remove 100% of the incoming waste load and as a result, many organisms still remain in the waste stream. To prevent the spread of waterborne diseases and also to minimise public health problems, disinfection may be required. Disinfection is treatment of the effluent for the destruction of all pathogens.

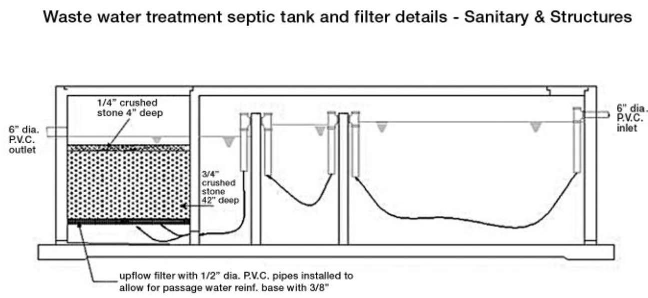
A variety of physical or chemical methods are capable of destroying microorganisms under certain conditions. Physical methods include heating to boiling or incineration or irradiation with X-rays or ultraviolet rays. Chemical methods might theoretically include the use of strong acids, alcohols, or a variety of oxidising chemicals or surface-active agents (such as special detergents).

In the past, wastewater treatment practices have principally relied on the use of chlorine for disinfection. The prevalent use of chlorine has come about because chlorine is an excellent disinfecting chemical and, until recently, has been available at a reasonable cost. However, the rising cost of chlorine coupled with the fact that chlorine even at low concentrations is toxic to fish and other biota as well as the possibility that potentially harmful chlorinated hydrocarbons may be formed has made chlorination less favoured as the disinfectant of choice in wastewater treatment. As a result there has been increased use of ozone (ozonation) or ultraviolet(UV) light as a disinfectant.

Ozone is a powerful disinfectant against viruses, protozoan cysts and vegetative bacteria. The short half-life of ozone also results in the rapid disappearance of any residual in the treated water.

Primary Process

Septic Tank with Upflow Filter



Source: Daniel & Daniel Engineering, Inc after Mara, D

Technology Description:

This is essentially a septic tank with an Upflow Filter that is incorporated directly after the second chamber of the septic tank. Effluent, after leaving the second chamber of the septic tank is directed upwards through the bottom of the filter before exiting to be disposed of to leach fields or otherwise. It is also mainly designed for on-site treatment of domestic sewage. In the upflow filter, the effluent enters at the base and flows up through the layer of coarse aggregate that is then discharged over a weir at the top. Anaerobic bacteria grow on the surface of the filter material and oxidise the effluent as it flows past. Disposal of the effluent may be into a stream or into soakage pits etc.

The effluent can have up to 70% reduction in BOD and it changes a highly turbid, grey to yellow influent into an odourless clear light yellow effluent. Both greywater and blackwater can be flushed through the system. Since septic tanks only accept liquid waste they must be connected to a flush toilet. To regulate the periodicity of discharge, a siphon can be installed.

Extent of Use:

Increasing use in the Caribbean (for example, Grenada, Barbados)

Operation and Maintenance:

- Filter may be expected to operate without maintenance for 18-24 months. Need to then drain filter and backwash it with freshwater.
- Septic tank needs regular desludging. Filter and the septic tank can be cleaned together. (see Septic tank O&M section)

Advantages:

- Improved effluent quality
- Disinfection efficiency increased
- Extends life of drain tile field (see section on Septic Tanks)

Disadvantages /constraints:

- Same as septic tanks
- Increased maintenance problems related to filters

Relative Cost:

- Slightly higher than traditional septic tanks

Cultural Acceptability:

- Generally accepted within the Caribbean Region

Energy use:

- NA

Pollution reduction:

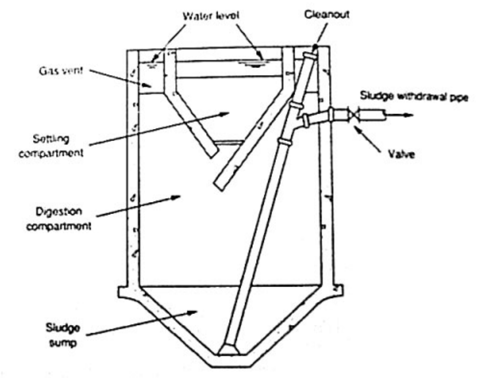
- 70% BOD and suspended solids removal

Suitability:

- Suitable for most applications

Primary Process

Imhoff Tanks



Source: Daniel & Daniel engineering, Inc

Technology Description:

Imhoff tanks are used for domestic or mixed wastewater flows. The Imhoff Tank consists of a two-story tank in which sedimentation is accomplished in the upper compartment and digestion of the settled solids is accomplished in the lower compartment.

The Imhoff tank is divided into an upper settling compartment in which sedimentation of solids occurs. Sludge then falls through an opening at the bottom into the lower tank where it is digested anaerobically. Methane gas is produced in the process and is prevented from disturbing the settling process by being deflected by baffles into the gas vent channels. Effluent is odourless because the suspended and dissolved solids in the effluent do not come into contact with the active sludge causing it to become foul. When sludge is removed it needs to be further treated in drying beds or other such device, for pathogen control.

The treatment efficiency is equivalent to primary treatment. It can achieve 40% BOD reduction, 65% Suspended solids reduction.

Extent of Use:

Limited use in the Caribbean Region (for example, Jamaica)

Operation and Maintenance:

- Requires removal of scum and sludge at regular intervals.

Advantages:

- Improved effluent quality compared to a sedimentation basin
- Can handle variance in organic loading
- Low land space required
- Produces stablised sludge
- No energy required
- Excellent primary treatment

Disadvantages /constraints:

- Effluent requires tertiary treatment

Relative Cost:

- Low capital cost Region
- Low operation cost

Cultural Acceptability:

- Is generally accepted within the Caribbean

Energy Usage:

- Energy generated but not captured

Pollution Reduction:

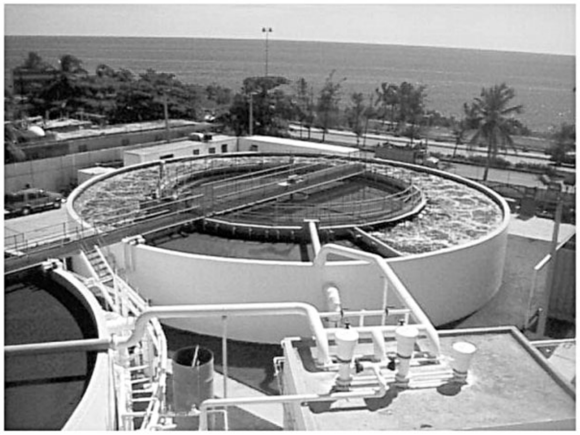
- 40% BOD and 65% SS removal

Suitability/Appropriateness

- Relatively small scale on site industrial waste and sewage

Secondary Process

Activated Sludge Treatment



Daniel & Daniel Engineering compliments US consulting Firm

Technology Description:

Operationally, biological waste treatment with the Activated Sludge Process uses an aeration basin and a secondary clarifier. Organic waste is introduced into a reactor where an aerobic bacterial culture is maintained in suspension. The reactor contents are referred to as the "mixed liquor." In the reactor, the bacterial culture carries out the conversion of organic matter and nutrients utilising oxygen to produce new bacterial cells. The new bacterial cells are further converted to carbon dioxide, water, ammonia and energy.

The aerobic environment in the reactor is achieved by the use of diffused or mechanical aeration, which also serves to maintain the mixed liquor in a completely mixed regime. After a specific period of time, the mixture of new cells and old cells is passed into a settling tank, where the cells are separated from the treated wastewater. A portion of settled cells is recycled to maintain the desired concentration of organisms in the reactor and a portion is wasted.

There are various types of activated sludge processes. These are complete mix, conventional, Step aeration, Pure Oxygen, Sequencing batch reactor, Contact Stabilisation, Extended Aeration and Oxidation Ditch.

Extent of Use: Widely used in the Caribbean

Operation and Maintenance: Skilled labour is required

Advantages:
- High Effluent Quality

Disadvantages /constraints:
- Energy requirement is high
- Highly skilled labour is required for O&M

Relative Cost:
- High Capital Cost
- High Operation & Maintenance cost

Cultural Acceptability:
- Widely accepted in the Caribbean

Energy Cost:
- Energy is required continuously for bacterial activity

Pollution Reduction:
- >80 % removal of Organic Matter and Suspended Solids

Suitability:
- Suitable for most situations – Housing Developments, Industries, Institutions etc.

Secondary Process

Pond Systems:

The following set of technology matrices describe a series of ponds: anaerobic, facultative and maturation pond systems. Generally, to achieve effluent quality suitable for discharge into receiving water bodies' ponds are designed in series, that is as a system and not singularly.

A. Anaerobic Ponds

Technology Description:

Anaerobic ponds are biological processes for treating wastewater (see UASB), are generally used as the first in a series of ponds to treat high strength wastewater (50-500kgBOD/ (ha.day)) and are usually highly loaded. Anaerobic stabilisation is the main process, which takes place. Further sedimentation of suspended matter also occurs. Because no aeration is necessary, anaerobic ponds can be as deep as technically feasible. The depth of anaerobic ponds ranges from 2-5 metres, which means a relatively small surface, compared to other pond types. Depending on the soil type, ponds are lined to prevent contamination of groundwater. The pond depth decreases light penetration to the deeper layers reducing the rate of oxygenation.

Effluents from anaerobic systems require further aerobic treatment before discharge to surface water bodies.

Extent of Use:

Increasing use in the Caribbean Region

Operation and Maintenance:

- Low degree of operation and maintenance required

Advantages:

- Low capital cost
- Low maintenance and O & M costs
- Effective removal of organic load
- Simple operation

Disadvantages /constraints:

- Land space
- Odour and insect nuisance
- Additional treatment step required

Relative Cost:

- Low capital cost compared to conventional anaerobic treatment systems.
  Low O & M costs

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

Energy Usage:

- None required if gravity fed

Pollution Reduction:

- 70-80% BOD Removal

Suitability:

- Pre-treatment of high strength industrial or municipal wastewater
- When land available and relatively inexpensive

Pond Systems:

B. Facultative Ponds

(Oxidation/Waste Stabilisation Ponds)

Technology Description:

These systems require much greater areas of land than the more compact and conventional trickling filters and Aerobic Stabilisation Ponds. Facultative ponds offer an option for considerably lower capital cost and relatively low operating and maintenance cost for effective treatment of wastewater. These ponds are predominantly used in municipal treatment systems or are often used as the second in a series of ponds. Facultative ponds treat waste in the range of 50-150kg BOD/ (ha.day). The pond depth is in the range of 1-2.5 meters with detention times rating from 20-60 days. Depending on the soil type, ponds are lined to prevent contamination of groundwater.

A biological process for treating wastewater, the ponds are called facultative because of their combined aerobic and anaerobic action. The oxygen supplied for the aerobic process is obtained either mechanically through aerators (high rate aerobic ponds) or through algal growth. Influent waste organic matter is broken down by aerobic heterotrophic bacteria. The resulting degradation products are used by algae, which also use light as a source of energy to synthesise algal cells by photosynthesis releasing oxygen to satisfy the demand of the aerobic biodegradation process. Near to the bottom of the pond, suspended matter settles and anaerobic conditions exist.

Unless the algae are harvested, total carbon in the effluent will be similar to influent. Often such discharges are used for irrigation or in constructed wetlands.

Extent of Use:

Increasing use in the Caribbean Region.

Operation and Maintenance:

- Relatively high degree of operation and maintenance required if algae harvested or mechanical aerator used for supplying oxygen

Advantages:

- Low capital cost
- Effective removal of organic load
- Simple operation

Disadvantages /constraints:

- Land space
- Insect nuisance
- Harvesting algal biomass

Relative Cost:

- Low capital cost compared to conventional aerobic treatment systems.

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

Energy Usage:

- Relatively high if mechanical aerators are used

Pollution Reduction:

- 70-95 % BOD Removal

Suitability

- Municipal wastewater
- Land available and relatively inexpensive
- Effluent discharge for irrigation or in constructed wetland

Pond Systems:

C. Maturation Ponds

Technology Description:
Maturation Ponds are low loaded lagoons (50-150kg BOD/ (ha.day) in which the effluent from facultative ponds are polished. Kjeldahl nitrogen is oxidised and pathogens die off to a great extent due to long retention times.

Extent of Use:
Increasing use in the Caribbean Region

Operation and Maintenance:
- Low degree of operation and maintenance required

Advantages:
- Low capital cost
- Low maintenance and O & M costs
- Removal of nitrogen and bacteria
- Simple operation

Disadvantages /constraints:
- Land space
- Harvesting algae

Relative Cost:
- Low capital cost compared to conventional aerobic treatment systems.
- Low O & M costs

Cultural Acceptability:
- Is generally accepted within the Caribbean Region

Energy Usage:
- None required if gravity fed

Pollution Reduction:
- Significant removal of microbes and nitrogen

Suitability:
- Polishing of industrial/municipal wastewater
- Land available and relatively inexpensive

Facultative and maturation ponds in series for treatment of municipal wastewater in a city in Jamaica.

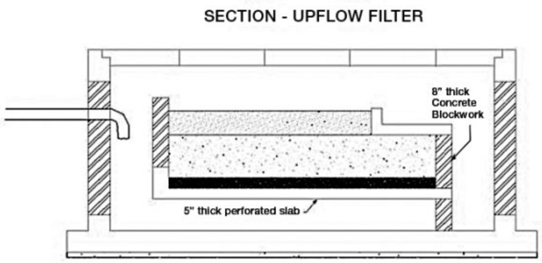
(Photograph provided by UCYConcepts@aol.com)

Aerobic Lagoons, St. Lucia (Courtesy CEHI)

Secondary Process

Filters

Anaerobic Filters/Fixed Bed Reactor/Fixed Film Reactor



A section of an Anaerobic Filter

Source: Daniel and Daniel Engineering Inc.

Technology Description:
The anaerobic filter is suitable for domestic and all industrial wastewater that has been pre-treated to achieve a suspended solids limit less than 100 mg/L. These filters allow the treatment of non-settleable and dissolved solids by bringing them into close contact with surplus active bacterial mass. Bacteria digest the dispersed or dissolved organic matter within short retention times. Bacteria fix themselves to filter material like gravel, rocks, cinder etc. allowing incoming wastewater to come into contact with active bacteria. Typical effluent quality is moderate with a 70-90% BOD removal in a well-operated anaerobic filter.

Extent of Use: Limited use in the Caribbean Region

Operation and Maintenance:
- Desludging required at regular intervals (18-24 months)
- Cleaning of filter material required

Advantages:
- Improved effluent quality
- Potential energy recovery
- Low land requirement
- Low mechanical content
- Can obtain materials locally

Disadvantages /constraints:
- Intensive operation and maintenance requirements

Relative Cost:
- Low to moderate capital cost and low O&M costs

Cultural Acceptability:
- Is generally accepted within the Caribbean Region

Energy use:
- Potential for energy recovery

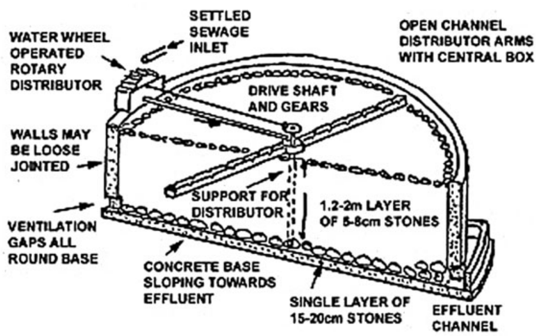
Pollution reduction:
- 70-90% BOD removal

Suitability:
- Wide application

Secondary Process

Filters

Trickling Filters/Percolating Filters



Source: After Mann, H.T., Williamson, D., 1982

Technology Description:

Trickling filters follow the same principle as the anaerobic filter as it provides a large surface for bacteria to settle, however it is an aerobic process. The Trickling filter consists of either a rock, gravel or plastic medium filling the filters.

The organic pollution in wastes is consumed by organisms that grow in a thin biological film over the media. Oxygen is obtained by direct diffusion from air into the thin biological film. To ensure that bacteria are allowed equal access to air and wastewater, wastewater is dosed in intervals to allow time for both wastewater and air to enter the reactor. Wastewater also needs to be equally distributed over the entire surface to fully utilise the media in the filter.

Preliminary settlement of sewage is required after which it is dosed by mechanical means (typically a rotating arm) over the surface of the filters.

Extent of Use:

Moderately used in the Caribbean (for example Trinidad and Tobago, St. Lucia, Jamaica)

Operation and Maintenance:

- Dead sludge has to be sloughed from time to time to prevent clogging
- Skilled technician required
- Maintenance of moving parts required

Advantages:

- High effluent quality
- Handles shock loads
- Oxygenation via a natural air draft

Disadvantages /constraints:

- Moderate operation and maintenance requirements
- Potential for fly nuisance

Relative Cost:

- Lower capital and O&M costs than conventional activated sludge system

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

Energy use:

- Low to moderate electricity use

Pollution reduction:

- 80% BOD removal

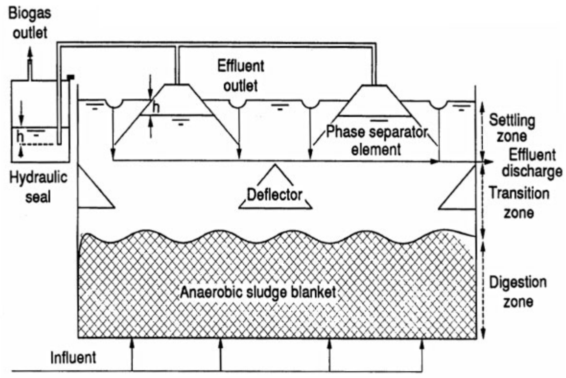
Suitability:

- Wide application for domestic and industrial wastewater uses

Secondary Process

UASB

Upflow Anaerobic Sludge Blanket



Source: SRC www.jawmanins.com

UASB, Scientific Research Council, Food Technology Institute, Kingston, Jamaica

Technology Description:

The Upflow Anaerobic Sludge Blanket Reactor is a high rate anaerobic treatment system (which can facilitate high loading and short retention time). It is utilised on both a small and large scale

The UASB process is characterised by an active sludge blanket/bed at the bottom of the reactor that degrades the incoming wastewater. The bacteria may spontaneously agglomerate to form granules. These granules have good settling properties and are not susceptible to being washed from the system under normal conditions. Retention of active sludge, either granular or flocculent within the UASB reactor enables good treatment at a high organic loading rate. The maintenance of high sludge concentration in the reactor is one of the most important conditions of a UASB process. The higher the concentration of viable sludge, the higher will be the conversion.

Extent of Use:

In Jamaica for agro-industrial wastewater and centralised sewerage systems

Operation and Maintenance:

- Medium to high degree of operation and maintenance required
- Highly skilled personnel required
- In start up period, monitoring and control critical
- Gas must be scrubbed before use

Advantages:

- Low production of stabilised sludge
- High treatment efficiency
- No energy required for treatment
- Relatively low capital and operating costs
- Energy recovery

Disadvantages /constraints:

- Start up time not immediate (3-6 months)

Relative Cost:

- Low capital cost (US$ 250-500/cubic meter)
- Low operation cost

Cultural Acceptability:

- Limited acceptance within the Caribbean Region (due in part to lack of exposure)

Energy Usage:

- Generated energy 0.35 m^3 methane/kg COD removed

Pollution Reduction:

- > 85% BOD and SS removal

Suitability/Appropriateness

- High strength organic waste, Utilised on small and large scale

Industrial/Agricultural Waste
Pond UASB

500 m^3 UASB-Reactor for Cane Sugar Wasterwater Treatment, Jamaica

Source: SRC www.jawmanins.com & UCYConcepts@aol.com

Technology Description:

The Pond Upflow Anaerobic Sludge Blanket Reactor is a high rate anaerobic treatment system (which can facilitate high loading and short retention time). It is utilised on both a small and large scale.

The Pond UASB process is the same as for the UASB and is characterised by an active sludge blanket/bed at the bottom of the reactor that degrades the incoming wastewater. The bacteria may spontaneously agglomerate to form granules. These granules have good settling properties and are not susceptible to being washed from the system under practical conditions. Retention of active sludge, either granular or flocculent within the UASB reactor enables good treatment at high organic loading rate. The maintenance of high sludge concentration in the reactor is one of the most important conditions of a UASB process. The higher the concentration of viable sludge, the higher will be the conversion.

Extent of Use:

In Jamaica for pilot plant sugar factory waste and animal waste

Operation and Maintenance:

- Medium to high degree of operation and maintenance required
- High skilled personnel required
- In start up period monitoring and control critical
- Gas scrubbed before use

Advantages:

- Low production and stabilised sludge
- High treatment efficiency
- No energy required for treatment
- Low capital and operating costs
- Construction time considerably shortened
- Modular components, adaptable during operation

Disadvantages /constraints:

- Effluent requires tertiary treatment
- Start up time not immediate (3-6 months)

Relative Cost:

- Low capital cost (US$ 100/m^3)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within Jamaica

Energy Usage:

- Generate energy 0.5 m^3/kg COD removal

Pollution Reduction:

- > 85% BOD and SS removal

Suitability/Appropriateness

- High strength organic waste, Utilised on small and large scale

PACKAGE PLANTS

Introduction

Package plants are pre-assembled wastewater treatment units, usually skid-mounted and transported to the site. There are several types of domestic wastewater package plants including:

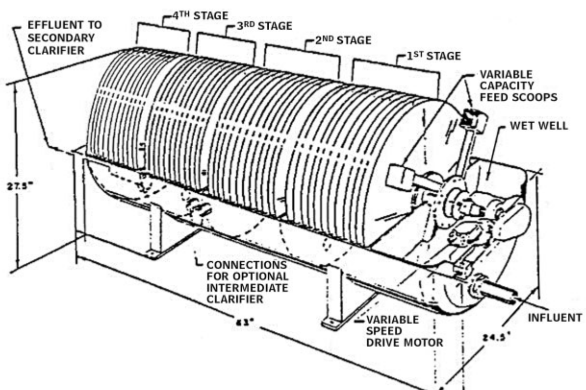
- Rotating Biological Contactors (RBC)
- Sequential Batch Reactors (SBR)
- Membrane Bioreactors (MBR)
- Aeration Units
- Modified Aeration Units

Details of various types of package plants are provided in the following sections.

Package Plant

Plant Type

Rotating Biological Contactors



Source: VSPGA 1985

Technology Description:

A rotating biological contactor consists of closely spaced circular disks of polystyrene or polyvinyl chloride. The disks are submerged in wastewater and rotated slowly through it.

In operation, biological growth becomes attached to the surfaces of the disks and eventually forms a slime layer over the entire wetted surface area of the disks. The rotation of the disks alternately contacts the biomass with the organic material in the wastewater and then with the atmosphere for adsorption of oxygen. The disk rotation affects oxygen transfer and maintains biomass in an aerobic condition. The rotation is also the mechanism for removing excess solids from the disks by shearing forces it creates and maintaining the sloughed solids in suspension so they can be carried from the unit to a clarifier. Rotating biological contactors can be used for secondary treatment and they can also be operated in seasonal and continuous–nitrification and denitrification modes.

Extent of Use:

Not widely used in the Caribbean. Used unsuccessfully in St. Lucia and St. Kitts

Operation and Maintenance:

Skilled labour is required

Advantages:

- High Effluent Quality

Disadvantages /constraints:

- Energy requirement is high
- Highly skilled labour is required for O&M

Relative Cost:

- High Capital Cost
- High Operation & Maintenance cost

Cultural Acceptability:

- Widely accepted in the Caribbean

Energy Cost:

- Energy is required on a 24/7 basis for bacterial activity

Pollution Reduction:

- >85 % removal of Organic Matter and Suspended Solids
- high levels of nutrient removal

Suitability:

- Suitable for most situations – Housing Development, Industries, Institutions etc.

Package Plant

Plant Type

Sequential Batch Reactors

Source: Cromaglass

Technology Description:

The Cromaglass Systems are essentially Sequencing Batch Reactors where treatment is by timed sequences within a single vessel. The unit consists of 3 sections each performing a different task.

In the first section (A) aeration occurs (Solids Retention).

This section is separated from the rest of the unit by a non-corrosive screen, which retains inorganic solids. Organic solids are broken up by turbulence created with mixed liquor being forced through the screen by a submersible aeration pump.

Section (B) is the continuing Aeration section where air and mixing are provided by pumps. An optional denitrification is performed under anoxic conditions by closing off air-to-air intake pumps, thus stopping aeration but allowing continual mixing.

The liquid is then transferred to section (C) the Clarification Section. When the clarification section is overfilled excess is spilled back into the aeration section. After this process, the clarifier is then isolated, solids settle and separate and effluent is pumped out of the Clarifier for discharge. Sludge is removed to a sludge processing unit.

Extent of Use: Limited use in the Caribbean Region. Growing use in Antigua, St. Kitts, Trinidad & Tobago, Barbados and St. Lucia

Operation and Maintenance:

- High operation and maintenance.
- High technology requiring skilled installation

Advantages:

- Low land space required
- High effluent quality
- Agents available within the region

Disadvantages /constraints:

- High operation and maintenance
- Requires electricity
- High technology requiring skilled operation and maintenance inputs.

Relative Cost:

- High

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

Suitability:

- Since only receives liquid waste, not suitable where water scarce or unreliable.
- Where skilled technical backup is available

Pollution Reduction:

- Treatment achieves over 90-95% reduction of BOD and Suspended Solids. The resulting effluent quality has BOD5 – 30mg/L, Total Suspendable Solids 30mg/L.

Package Plant

Plant Type

Membrane Bioreactor

Source:New Water Inc.

Technology Description:

Membrane Bioreactor Systems utilise filtration technology to replace the traditional secondary clarifier and sand filters in conventional secondary treatment systems. Typically these can be engineered to meet the needs of wastewater treatment and water reuse plants, with average daily flows of less than 400,000Lpd to over 4 MLpd.

ZeeMOD™ is constructed around four basic building blocks: the biological treatment reactor, a fine screen trash interceptor, the modular membrane units and the pre-assembled equipment skid.

Typical Treated Water Results:

BOD < 5 mg/L
TSS < 5 mg/L
TN < 5 mg/L
TP < 5 mg/L
Turbidity < 1 NTU

Extent of Use:

Increasing use in the Caribbean region

Operation and Maintenance:

- Moderate operation and maintenance costs
- Requires minimal operator supervision

Advantages:

- Extremely low space requirements
- Consistent high quality effluent
- High tolerance of cyclic and/or shock loadings
- Agents available within the region

Disadvantages /constraints:

- Requires a reliable water supply
- Requires electricity

Relative Cost:

- Moderate

Cultural Acceptability:

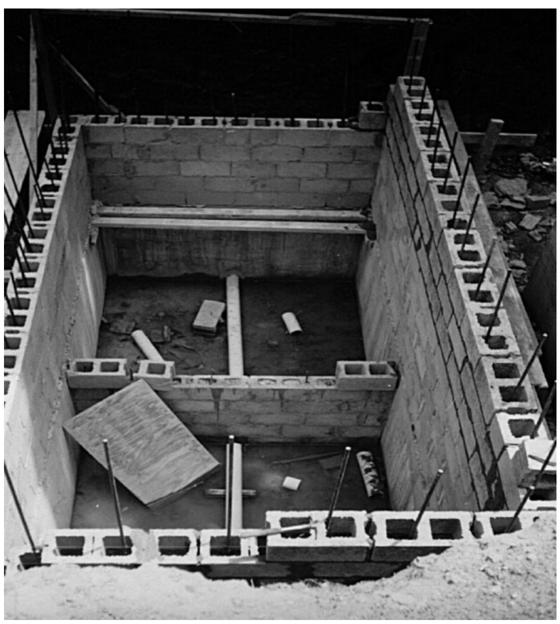
- Increasing acceptance within the region.

Suitability:

- Wherever water reuse is desired or where efficient high quality treatment is required.

Tertiary Process

Intermittent Slow Sand filters



Source: Daniel and Daniel Engineering Inc.

Technology Description:

Intermittent sand filters are designed for on-site treatment of domestic and mixed wastewaters. The process may be defined as the intermittent application of wastewater to a bed of granular material (sand), which is under-drained to collect and discharge the final effluent. The process is one of polishing wastewater that has passed through primary and secondary treatment and which produces effluent of very high quality.

The mechanisms of purification attained by intermittent filtration are very complex since filters entrap, sorb and assimilate materials in the wastewater. It is not surprising to find that the interstices between the grains may be filled and eventually the filter will clog.

The degree of stabilisation attained from an intermittent sand filter is dependant upon; (1) the type and biodegradability of the wastewater, (2) the environmental conditions within the filter and (3) the design characteristics of the filter.

Re-aeration and temperature are two of the most important environmental conditions that affect the degree of wastewater purification through an intermittent filter. Hence the filter is oxygenated via vent pipes, which ensure aerobic conditions at the bottom of the filter. Temperature directly affects the rate of microbial growth, chemical reactions and the adsorption mechanism. The temperatures experienced in the Caribbean are adequate enough for best performance.

It is recommended that the filter media effective size range be from 0.25 mm up to 1.5 mm. Uniformity coefficients (UC) for the grain sizes of the media normally should be less than 4.0. Uniformity coefficients (UC)) for intermittent filter media normally should also be less than 4.0.

The hydraulic loading rate may be defined as the volume of the liquid applied to the surface area of the sand filter over a designated length of time, which is typically 0.3 - 0.6 $m^3/m^2/d$ (0.75 - 15 gpd/ft^2). The organic loading rate is not very well defined in the literature.

Generally the depth of the media ranges from 1.3m - 3m (4'- 10') but pilot studies indicate that the purification of wastewater occurs in the top 23 - 30cm (9 - 12"). Most bed depths used today range from 0.6 - 1.1m (24 - 42").

Sufficient resting must also be provided between dosages to obtain aerobic conditions. Dosing methods can include ridge and furrow, drain tile distribution, surface flooding and spray distribution. For best results a minimum of two dosings per day is recommended for media with a grain size greater than 0.45mm.

Extent of Use:
Widely used in the Caribbean Region (for example Grenada and Trinidad and Tobago)

Operation & Maintenance Requirements:

- For Intermittent Filters: Free access, with removable covers
- Filter Media Raking: once every 3 months, 8cm (3") deep
- Filter media replacement: Replace when wastewater is ponding more than 30cm (12"), replace the top 5 - 8cm (2-3") of sand.
- Pumps and controls (if any): According to manufacturers specification and local conditions
- Pipe Fittings and other Appurtenances: Check every 3 months.

Advantages:

- High effluent quality
- Can be constructed with material that can be found locally
- Can be operated by semi-skilled operators
- Flexibility in the siting of the system

Disadvantages /constraints:

- Correct grading of the media may not readily be found
- After 3-6 months the dirty layer must be manually scrapped off, washed and sand replaced

Relative Cost:

- Low to moderate capital cost
- Low O&M costs

Cultural Acceptability:

- Accepted within the Caribbean Region

Energy Usage:

- Low - Electricity if a pump is needed to raise the wastewater out of ground or to higher elevation for irrigation

Pollution Reduction:

- Reduces BOD, SS, pathogenic organisms and nutrients in the effluent.
- Removal ratios of BOD, SS and pathogenic organisms are on the order of 95%

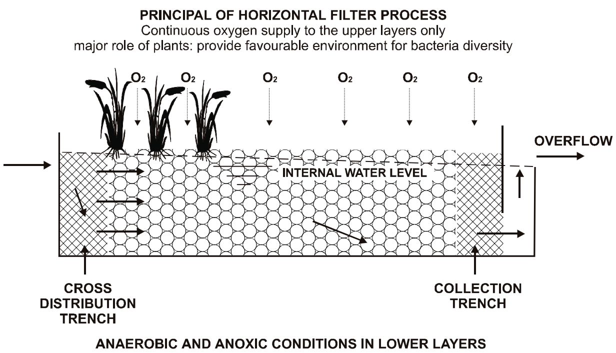
Suitability:

- Wide application
- Suitable as a tertiary treatment step before water is disinfected by chlorine or UV where water reuse is required

<u>Tertiary Process</u>

Constructed Wetland

(Reed Bed System/Subsurface Flow/Wetlands/Root Zone Treatment Plants/Horizontal Gravel Filter)



Source: Principle of the Horizontal Filter after Ludwig, S. 1998

Technology Description:

Wetland systems are suitable for domestic and industrial wastewater that has undergone primary and/or secondary treatment and has a COD content less than 500mg/L. The reed bed system consists of a 1m deep basin sealed with clay or some other form of lining to prevent percolation into groundwater with the basin itself being filled with graded aggregate in which reeds are then planted. Types of reeds utilised in the Caribbean region are bullrush, cattail etc.

Oxygen is transported through the pores of the plant down to the roots whereby the oxygen content increases the biological activity of the soil. When wastewater passes through the root zone and aggregates, organic compounds, nutrients and pathogenic organisms are eliminated.

The effluent quality achieved is up to 85% BOD and COD removal, greater than 95% pathogen removal with significant nutrient content removed.

Extent of Use: Moderate use within the Caribbean Region (for example, St. Lucia, Grenada, Jamaica). Increasingly being recommended.

Operation and Maintenance:

- Generally low operation and maintenance required, however does need maintaining of reeds or wetland plants to keep weeds out and keep good growth

Advantages:

- Nutrient and pathogen removal
- Low operation and maintenance requirements
- No energy requirements
- Effluent suitable for discharge in sensitive water bodies or reuse
- Construction material generally available locally
- Aesthetically pleasing
- Provides habitat for birds and aquatic life

Disadvantages /constraints:

- Large land area required
- Manual harvesting of reeds required
- Creates potential environment for insect breeding

Relative Cost:

- Low capital and O&M costs

Cultural Acceptability:

- Growing acceptance based on wider exposure within the Caribbean Region

Energy use:

- None

Pollution reduction:

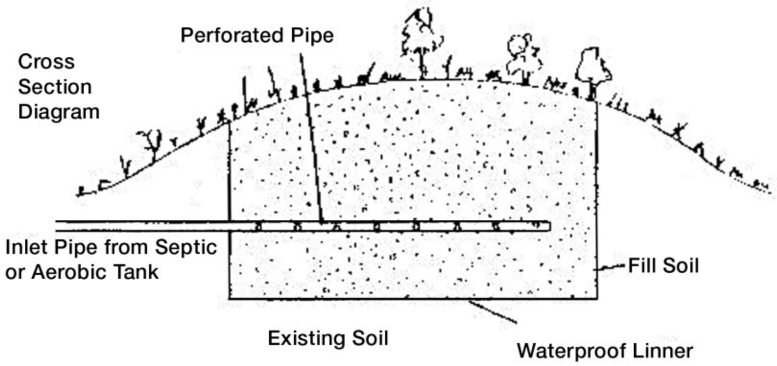
- 85% BOD and COD removal, greater than 95% pathogen removal with significant nutrient content removed.

Suitability:

- Wide application

Tertiary Process

Evapo-Transpiration Beds



Evapo-Transpiration Bed
(Used with Septic or Aerobic Tank)
sand bed is lined with plastic or other waterproof material. Bed could be mound or level. Liquid evaporates because liner prevents it from filtering through natural soil. Plants speed evaporation by drawing moisture from soil and breathing it into the air. Used where conventional absorption field not possible.

Technology Description:

The Evapo-transpiration Bed is a subsurface flow system designed with slopes of 1 % or slightly higher. The basin is excavated, lined (to reduce/prevent infiltration into the ground water) and packed with a porous medium (usually gravel). A layer of soil then covers the Evapo-transpiration Bed.

The main objective of the system is to treat the effluent leaving a secondary or advanced primary system by removing the remaining organic matter, nutrients and faecal coliform.

Treatment of the water in the Evapo-transpiration Bed takes place through the porous medium, the gravel. The vegetation plays a role by transferring oxygen through its roots to the bottom of the basin and providing a surface, in addition to the gravel, for attachment of the bacteria that performs most of the water treatment.

A properly sized Evapo-transpiration Bed would not have any effluent leaving the system as most water would either be evaporated or taken up by the roots of the plants, which would loose water through the leaves by transpiration.

Extent of Use:

Widely used in the Caribbean

Operation and Maintenance:

- No maintenance of system is required. System can be designed in a manner to prevent the outflow of effluent if effluent is not needed.

Advantages:

- High Effluent Quality
- Land area is re-created as a green area

Disadvantages /constraints:

- Large land requirement

Relative Cost:

- Low cost

Cultural Acceptability:

- Widely accepted in the Caribbean

Energy Cost:

- No energy required

Pollution Reduction:

- 99 % Faecal Coliform
- Polishing of organic matter and nutrients

Suitability:

- Suitable for most situations where land is available – Housing Development, Institutions etc.

4.4 Wastewater Reuse

The reuse of wastewater in agriculture and aquaculture has much potential and is used throughout the world. It can replace the use of limited freshwater for the irrigation of crops or be used as an additional source of nutrients to increase production of horticulture and forestry crops. Aquaculture is becoming popular and may provide additional economic opportunities in developing countries. Nutrients found in wastewater discharges, that normally pollute the environment, are beneficial when used with irrigation and aquaculture applications. However the reuse of wastewater is currently not widely practiced in the Caribbean Region. With many countries suffering from limited water resources, the reuse of wastewater would provide benefits through both conserving water and reducing pollution potential to marine and surface water resources.

There is potential in other countries to use wastewater to irrigate sugarcane and/or for fish farming. However these rural activities are generally remote from urban centres where treated wastewater is available. Caribbean SIDS, whose priorities are to provide appropriate and affordable sanitation facilities should explore all possibilities to reuse wastewater wherever possible.

In some countries there are strong traditional feelings against the reuse of wastewater. Much talking and convincing may be required to introduce this concept. The issue of 'most appropriate' technology needs to be explored and thoroughly discussed with potential users before proceeding with any new development. Also, irrigation is not practiced extensively in the Caribbean and therefore water for irrigation use may not be a high priority in some of these countries.

Wastewater is a valuable resource and its reuse in the horticulture, forestry and aquaculture industries should be encouraged. Reduction in environmental pollution as well as increased production would result. However adequate health safeguards are required regarding wastewater treatment, crop restriction, appropriate application methods and human exposure control. The WHO (1989) Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture, should be consulted to ensure that any reuse of wastewater is safe for those who use reused wastewater and those who consume food products grown with reused wastewater (i.e. eating contaminated crops or eating animals that have fed on contaminated crops or developed in wastewater ponds).

For additional information on the reuse of wastewater visit the Integrated Bio-System Network at http://www.ias.unu.edu/proceedings/icibs/ibs/ibsnet/. This is a network of people, connected via the Internet, for forum and cooperation in the application of integrated bio-systems in agriculture, industry, forestry and habitat.

The application of wastewater to land may be by:

Surface flow: Wastewater is applied at one end of an area and allowing it to spread to the other end by gravity. Runoff control may be a problem.

Sprinkler distribution: Wastewater is applied by over-ground sprinklers (either stationary or moving). Normally pumping is required and as a result aerosols may be produced.

Subsurface and localised irrigation: This includes the use of drip and trickle irrigation methods which require a good quality effluent to avoid clogging. Using these methods could reduce microbial contamination of crops.

The following table provides information on selecting a suitable application method for land disposal of wastewater.

Table 6: Factors affecting choice of irrigation method and special measures required when wastewater is used

Irrigation Method	Factors Affecting Choice	Special Measures for Wastewater
Border (flooding) irrigation	Lowest cost, exact levelling not required	Thorough protection for field workers, crop handlers and consumers
Furrow irrigation	Low cost levelling may be needed	Protection for field workers, possible crop handlers and consumers
Sprinkler irrigation	Medium water use efficiency, levelling not required	Some crops, especially tree fruit, should not be grown. Minimum distance 50 – 100m from houses and roads. Anaerobic wastes should not be used because of odour nuisance.
Subsurface and localised irrigation	High cost, high water use efficiency, higher yields	Filtration to prevent clogging of emitters

Source: Mara and Cairncross, (1989)

4.5 Sludge Management

The constituents removed in wastewater treatment plants include screenings, grit, scum and sludge. The sludge resulting from wastewater treatment operations and processes is usually in the form of a liquid or semisolid liquid that typically contains from 0.25% to 12% solids by weight, depending on the operations and processes used. Of the constituents removed by treatment, sludge is by far the largest volume and its processing and disposal is perhaps the greatest challenge facing personnel in the field of wastewater treatment.

The challenges in dealing with sludge are generally as a result of its characteristics. It is composed largely of the substances responsible for the offensive character of untreated wastewater. The portion of sludge produced from biological treatment requiring disposal is composed of the organic matter contained in the wastewater but in another form, which can also decompose and become offensive. Only a small part of the sludge is solid matter.

There are several methods used to process and dispose of sludge. Thickening (concentration), conditioning, dewatering and drying are used primarily to remove moisture from sludge; digestion, composting, incineration, wet-air oxidation and vertical tube reactors are used primarily to treat or stabilise the organic material in the sludge.

Solids and Sludge Sources, Characteristics and Quantities

To design sludge processing, treatment and disposal facilities properly, the sources, characteristics and quantities of the solids and sludge to be handled must be known.

Sources

The sources of solids in a treatment plant vary according to the type of plant and its method of operation. The principal sources of solids and sludge and the types generated are outlined in **Table 7**. For example, in a complete mixed-liquor activated sludge process, if sludge wasting is accomplished from the mixed-liquor line or aeration chamber, the activated-sludge settling tank is not a source of sludge. On the other hand, if wasting is accomplished from the solids return line, the activated-sludge settling tank constitutes a sludge source. If the sludge from the mixed-liquor line or aeration chamber is returned to the primary settling tank for thickening, this may obviate the need for a thickener, reducing by one the number of independent sludge sources in the treatment plant. Processes used for thickening, digesting, conditioning and dewatering the sludge produced from primary and secondary settling tanks also constitute sludge sources.

Table 7: Sources of solids and sludge from a conventional wastewater treatment plant

Unit operation or process	Types of solids or sludge
Screening	Coarse solids
Grit removal	Grit and scum
Pre-aeration	Grit and scum
Primary sedimentation	Primary sludge and scum
Biological treatment	Suspended solids
Secondary sedimentation	Secondary sludge and scum
Sludge-processing facilities	Sludge, compost and ashes

Characteristics

To treat and dispose of the sludge produced from wastewater treatment plants in the most effective manner, it is important to know the characteristics of the solids and sludge that will be processed. The characteristics vary depending on the origin of the solids and sludge, the amount of ageing that has taken place and the type of processing to which they have been subjected.

General Composition

Many of the chemical constituents, including nutrients, are important in considering the ultimate disposal of the processed sludge and the liquid removed from the sludge during processing. The measurement of pH, alkalinity and organic acid content are important in process control of anaerobic digestion. The content of heavy metals, pesticides and hydrocarbon has to be determined when incineration and land application methods are considered. The energy (thermal) content of sludge is important where a thermal reduction process such as incineration is considered.

Specific Constituents

Characteristics of sludge that affect its suitability for land application and beneficial use include organic content (usually measured as volatile solids), nutrients, pathogens, metals and toxic organics. The fertiliser value of sludge, which should be evaluated where the sludge is to be used as a soil conditioner, is based primarily on the content of nitrogen, phosphorus and potassium (potash). Typical nutrient values of sludge as compared to commercial fertilisers are listed in **Table 8.**

Table 8: Comparison of nutrient levels in commercial fertilisers and wastewater sludge

	Nitrogen	Nutrients % Phosphorus	Potassium
Fertilisers for typical agricultural use*	5	10	10
Typical values for stabilised wastewater sludge	3.3	2.3	0.3

**The concentrations of nutrients may vary widely depending upon the soil and crop needs*

In most land application systems, sludge provides sufficient nutrients for good plant growth. In some applications, the phosphorus and potassium content of wastewater sludge may be too low to satisfy specific plant uptake requirement.

Trace elements in sludge are those inorganic chemical elements that, in very small quantities, can be essential or detrimental to plants and animals. The term "heavy metals" is used to denote several of the trace elements present in sludge. Concentrations of heavy metals may vary widely. For land application of sludge, concentration of heavy metals may limit the sludge application rate and the useful life of the application site.

Quantity Variations

The quantity of solids entering the wastewater treatment plant daily may be expected to fluctuate over a wide range. To ensure capacity capable of handling these variations, the processing and disposal facilities should consider the following.

i. The average and maximum rates of sludge production and
ii. The potential storage capacity of the treatment units within the plant

A limited quantity of solids may be stored temporarily in the sedimentation and aeration tanks. The storage capacity can be used to equalise short-term peak loads. Where digestion tanks with varying levels are used, their large capacity provides a substantial dampening effect on peak digested sludge loads. In sludge treatment systems where digestion is used, the design is usually based on maximum monthly loadings. Where digestion is not used, the sludge treatment process should be capable of handling the solids production of the maximum week. Certain components of the sludge system, such as sludge pumping and thickening, may need to be sized to handle the maximum day conditions. The total quantities of sludge that must be processed are determined by preparing a series of solids balances for the treatment process.

Some Methods of Sludge Treatment include:

1. Anaerobic Sludge Digestion
2. Aerobic Sludge Digestion
3. Composting
4. Conditioning
5. Disinfection
6. Dewatering
7. Heat Drying
8. Thermal Reduction

1. Anaerobic Sludge Digestion

Anaerobic digestion is among the oldest forms of biological wastewater treatment. In the past heat was applied to separate digestion tanks and major improvements were made in the design of the tanks and associated appurtenances. It is interesting to note that the same practice is being followed today, but great progress has been made in the fundamental understanding and control of the process, the sizing of tanks and the design and application of equipment. Because of the emphasis on energy conservation and recovery and the desirability of obtaining beneficial use of wastewater sludge, anaerobic digestion continues to be the dominant sludge stabilisation process.

2. Aerobic Sludge Digestion

Aerobic digestion may be used to treat only the following:

i. waste activated sludge
ii. mixtures of waste activated sludge or trickling-filter sludge and primary sludge
iii. waste sludge from extended aeration plants, or
iv. Activated-sludge treatment plants designed without primary settling.

Aerobic digestion has been used primarily in plants of a size less than 5 Mgal/d (0.2 m^3/s), but in recent years the process has been employed in larger wastewater treatment plants.

Advantages claimed for aerobic sludge digestion as compared to anaerobic digestion are as follow:

i. volatile solids reduction is approximately equal to that obtained anaerobically;
ii. lower BOD concentrations in supernatant liquor;
iii. production of an odourless, humus-like, biologically stable end product;
iv. recovery of more of the basic fertiliser values in the sludge;
v. operation is relatively easy; and
vi. lower capital cost.

The major disadvantages of the aerobic digestion process are that:

i. a high power cost is associated with supplying the required oxygen;
ii. a digested sludge is produced with poor mechanical dewatering characteristics;
iii. the process is affected significantly by temperature, location and type of tank material.

An additional disadvantage is that a useful by-product such as methane is not recovered. In cases where separate sludge digestion is considered, aerobic digestion of biological sludge may be an attractive application.

3. Composting

Composting has received increased attention as a cost-effective and environmentally sound alternate for the stabilisation and ultimate disposal of wastewater sludge. Increasingly stringent air pollution regulations and sludge disposal requirements in some countries coupled with the anticipated shortage of available landfills have accelerated the development of composting as a viable sludge management option. Sludge that has been composted properly is a sanitary, nuisance-free, humus-like material. Approximately 20% to 30% of the volatile solids are converted to carbon dioxide and water. As the organic material in the sludge decomposes, the compost heats to temperatures in the pasteurisation range of 50°C to 70°C (120°F to 160°F) and enteric pathogenic organisms are destroyed. A properly composted sludge may be used as a soil conditioner in agricultural or horticultural applications or for final disposal, subject to any limitations based on constituents in the sludge.

Although composting may be accomplished under anaerobic or aerobic conditions, aerobic composting is used for essentially all municipal wastewater sludge applications. Aerobic composting accelerates material decomposition and results in the higher rise in temperature necessary for pathogenic destruction. Aerobic composting also minimises the potential for nuisance odours.

Other factors affecting the type of composting system are as follows:

i. the nature of the sludge produced;
ii. stabilisation, if any of the sludge prior to composting;
iii. type of dewatering equipment and chemical used
iv. the anticipated daily production of sludge from a wastewater treatment facility

Sludges that are stabilised by aerobic or anaerobic digestion prior to composting may reduce the size of the composting facilities by up to 40%.

4. Conditioning

Sludge is conditioned expressly to improve its dewatering characteristics. The two methods most commonly used involve the addition of chemicals and heat treatment. Other conditioning methods such as freezing, irradiation and solvent extraction have also been used experimentally.

5. Disinfection

Sludge disinfection is becoming an important consideration as an add-on process because of stricter regulations in some countries for the reuse and application of sludge on land. When sludge is applied to the land, protection of public health requires that contact with pathogenic organisms be controlled.

There are many ways to destroy pathogens in liquid and dewatered sludges. The following methods have been used internationally to achieve pathogens reduction beyond that attained by stabilisation.

- Pasteurisation
- Other thermal processes such as heat conditioning, heat drying, incineration, pyrolysis, or starved air combustion
- High pH treatment, typically with lime, at a pH higher than 12.0 for 3 hrs
- Long-term storage of liquid digested sludge
- Complete composting at temperatures above 55°C (131°F) and curing in a stockpile for at least 30 days
- Addition of chlorine to stabilise and disinfect sludge
- Disinfection with other chemicals
- Disinfection by high-energy irradiation

6. Dewatering

Dewatering is a physical (mechanical) unit operation used to reduce the moisture content of sludge for one or more of the following reasons:

- The costs for trucking sludge to the ultimate disposal site become substantially lower when sludge volume is reduced by dewatering.
- Dewatered sludge is generally easier to handle than thickened or liquid sludge. In most cases, dewatered sludge may be shovelled, moved about with tractors fitted with buckets and blades and transported by belt conveyors.
- Dewatering is required normally prior to the incineration of the sludge to increase the energy content by removal of excess moisture.
- Dewatering is required before composting to reduce the requirements for supplemental bulking agents or amendments.
- In some cases, removal of the excess moisture may be required to render the sludge odourless and non-putrescible.
- Sludge dewatering is required prior to landfilling in monofills to reduce leachate production at the landfill site.

A number of techniques are used in dewatering devices for removing moisture. Some rely on natural evaporation and percolation to dewater the solids. In mechanical dewatering devices, mechanically assisted physical means are used to dewater the sludge more quickly. The physical means include filtration, squeezing, capillary action, vacuum withdrawal and centrifugal separation and compaction. The available dewatering processes include vacuum filters, centrifuges, belt filter presses, recessed plate filter presses, drying beds and lagoon.

7. Heat Drying

Sludge drying is a unit operation that involves reducing water content by vapourisation of water to the air. In conventional sludge drying beds, vapour pressure differences account for evaporation to the atmosphere. In mechanical drying apparatuses, auxiliary heat is provided to increase the vapour-holding capacity of the ambient air and to provide the latent heat necessary for evaporation. The purpose of heat drying is to remove the moisture from the wet sludge so that it can be incinerated efficiently or processed into fertiliser. Drying is necessary in fertiliser manufacturing so as to permit the grinding of the sludge, to reduce its weight and to prevent continued biological action. The moisture content of the dried sludge is less than 10%.

8. Thermal Reduction

Thermal reduction of sludge involves the following:
- The total or partial conversion of organic solids to oxidised end products, primarily carbon dioxide and water, by incineration or wet-air oxidation or
- The partial oxidation and volatilisation of organic solids by pyrolysis or starved-air combustion to end products with energy content.

The major advantages of thermal reduction are:
- Maximum volume reduction, thereby lessening the disposal requirements,
- Destruction of pathogens and toxic compounds and
- Energy recovery potential.

Disadvantages cited include the following:
- High capital and operating cost
- Highly skilled operating and maintenance staff is required
- The residuals produced (air emissions and ash) may have adverse environmental effects and
- Disposal of residuals, which may be classified as hazardous wastes, may be uncertain and expensive.

Thermal reduction processes are used most commonly by medium-to-large sized plants with limited ultimate disposal options.

Sludges processed by thermal reduction are usually dewatered, untreated sludges. It is normally unnecessary to stabilise sludge before incineration. In fact, such practice may be detrimental because stabilisation, specifically aerobic and anaerobic digestion, decreases the volatile content of the sludge and consequently increases the requirement for an auxiliary fuel. An exception is the use of heat treatment ahead of incineration. Heat treated sludge dewaters extremely well, making the sludge autocombustible (i.e., no auxiliary fuel is required to sustain the burning process). Sludges may be subjected to thermal reduction separately or in combination with municipal solid wastes.

Sludge Treatment

Co-Composting

The Edmonton Co-Composting Facility
Courtesy: Stantec

Technology Description:

Co-Composting is a process in which composting of the organic portion of an organic waste is supplemented with a range of materials such as septage, sewage sludge and limited effluents from septage or sewage treatment facilities and in some instances sewage screenings. The process can vary in sophistication from a simple windrow and turning process to an enclosed reactor.

The main advantage to the use of bio-solids as additives to the organics is the supplementation of nitrogen to the mix. One of the key requirements for a successful compost operation is to provide the proper carbon/nitrogen (c:n) mix. Basic organics from MSW may not have enough nitrogen to provide the proper c:n ratio. Thus the addition of nitrogen through bio-solids can improve the process. Some examples of successful co-composting mixtures or recipes of residual waste streams are as follows:

The mixing of the sorted organic portion of municipal solid wastes (MSW) and secondary sewage sludge;
The mixing of septage solids with wood chips;
The mixing of abattoir wastes such as blood with shredded yard and garden waste;
The mixing of chicken manure with shredded yard and garden waste;
The spreading of septic tank pump out waste on MSW compost windrows; and
The mixing of fishery wastes with MSW organics.
Residual disposal needs combined with waste streams can produce a useful end product such as compost, landfill cover materials, etc.

Extent of Use:

Not yet used extensively in the Caribbean. Some pilot trials held in Barbados.

Operation and Maintenance:

- Operation and maintenance costs depend on whether a simple windrow composting system (low) is used versus a more sophisticated in-vessel composting technology (high).

Advantages:

- Allows for disposal of problematic wastes such as septage and animal offal
- Produces a useful end product

Disadvantages /constraints:

- Potential for odours, flies and vermin if the composting process is not operated effectively.

Relative Cost:

- Low

Cultural Acceptability:

- Increasing acceptance in the region

Suitability:

- Suitable for the treatment and disposal of special wastes with high BOD and nutrient content.

4.6 Wastewater Disposal Systems

The two main options for wastewater disposal are either into a body of water, through outfalls or on/into the land. In most Caribbean SIDS the sea is the main end point for wastewater disposal, either directly through piped outfalls or indirectly through groundwater discharges. For each of these options it is preferred that the wastewater has been treated to remove at least solids and grit that may cause blockages compounding the operation and maintenance of the system and causing visible pollution in receiving water bodies.

4.6.1 Sea/River Disposal

Because most of the Caribbean islands are blessed with good weather and beautiful climate, tourism plays, an important role in most of the islands economies. To satisfy this tourism need, in many of the islands, the hotels and guesthouses are being built on or near the coastline. This has resulted in wastewater disposal being a very important issue.

It is a well-known fact that the disposal of untreated or partially treated wastewater results in detrimental effects not only on the nearby environment but also on the receiving water body and public health.

In some of the islands, direct disposal at sea (untreated) is being practiced but in others attempts are being made to curtail this activity by improving the quality of the effluent before discharge.

In some islands, the existing wastewater facilities have outlived their usefulness due to outdated technology and inadequate and irregular maintenance. However, some attempts are being contemplated to upgrade and improve these facilities. Partially treated wastewaters are discharged in rivers and streams in some of the islands, but attempts are also being made to improve this practice.

Disposal of domestic wastewater to the Caribbean Sea is regulated by the Protocol Concerning Pollution From Land-Based Sources And Activities To The Convention For The Protection And Development of The Marine Environment of The Wider Caribbean Region (Cartagena Convention LBS Protocol). Annex III of the LBS Protocol sets standards for domestic wastewater discharging into Class I or Class II waters of the Caribbean Sea. The effluent standards required for Class 1 waters may be met by a minimum of secondary treatment, Class II might be met by a minimum of primary treatment while those for Class I waters, because of inherent or unique environmental characteristics or fragile biological or ecological characteristics or human use, are particularly sensitive to the impacts of domestic wastewater. Class II waters are less sensitive to these impacts. The LBS Standards are as follows:

Discharges into Class II Waters

Each Contracting Party shall ensure that domestic wastewater that discharges into, or adversely affects, Class II waters is treated by a new or existing domestic wastewater system whose effluent achieves the following effluent limitations based on a monthly average:

Table 9: Effluent Limits for Discharges into Class II Waters

Parameter	Effluent Limit
Total Suspended Solids	150 mg/L*
Biochemical Oxygen Demand (BOD_5)	150 mg/L
pH	5-10 pH units
Fats, Oil and Grease	50 mg/L
Floatables	not visible
** Does not include algae from treatment ponds*	

Discharges into Class I Waters

Each Contracting Party shall ensure that domestic wastewater that discharges into, or adversely affects, Class I waters is treated by a new or existing domestic wastewater system whose effluent achieves the following effluent limitations based on a monthly average:

Table 10: Effluent Limits for Discharges into Class I Waters

Parameter	Effluent Limit
Total Suspended Solids	30 mg/L*
Biochemical Oxygen Demand (BOD_5)	30 mg/L
pH	5-10 pH units
Fats, Oil and Grease	15 mg/L
Faecal Coliform (Parties may meet effluent limitations either for faecal coliform or for E. coli (freshwater) and enterococci (saline water))	Faecal Coliform: 200 mpn/100 mL; or a. E. coli: 126 organisms/100mL; b. enterococci: 35 organisms/100 mL
Floatables	not visible
** Does not include algae from treatment ponds*	

All Discharges

Each Contracting Party to the Cartagena Convention shall take into account the impact that total nitrogen and phosphorus and their compounds may have on the degradation of the Convention area and, to the extent practicable, take appropriate measures to control or reduce the amount of total nitrogen and phosphorus that is discharged into, or may adversely affect, the Convention area.

Each Party shall ensure that residual chlorine from domestic wastewater treatment systems is not discharged in concentrations or amounts that would be toxic to marine organisms that reside in or migrate to the Convention area.

Outfalls

Detrimental effects to the environment from areas that are sewered, with various degrees of treatment, may be minimised by using good effluent disposal practices. The location of ocean outfalls ideally should be beyond the reef, in high circulation areas and below the thermocline. All too often outfall locations are chosen based on other criteria (i.e. treatment plant or pump station locations) instead of using criteria that safely dispose of wastewater to minimise environmental effects. These basic design criteria should be investigated before the construction of any new system or the upgrading of an existing system to avoid problems that are currently being experienced by many Caribbean countries. While outfall disposals are still economically attractive, if not located and constructed properly, they may cause much environmental pollution of coastal areas that may have significance health, culture and economic consequences.

Discharges to rivers should not be allowed unless a high degree of initial wastewater treatment, river mixing and dilution is achieved.

4.6.2 Land Disposal

In the Caribbean islands, land disposal of wastewater is usually associated with on-site treatment of the waste using tile field, soakaway pits and evapotranspiration methods. For these methods to be successful, soil conditions play an important role. Percolation tests should be carried out to determine the rate at which the wastewater could infiltrate the soil. In some instances, soil is imported to improve percolation.

The availability of land space has been a mitigating factor for this type of wastewater disposal. It should be noted that when dealing with land disposal of wastewater, groundwater contamination and pollution should be of major concern. **Table 11** summarises some land disposal methods and **Table 12** compares effluent qualities from these methods.

Deep Well Injection

An alternative means of disposal is via deep wells on land. Deep well injection is used extensively in the Bahamas, where outfalls are not allowed. The wells may be from 50m-150m deep and may reach as far as the Oceanics layer. It is assumed that the wastewater is released to the sea at the point where the rock layer outcrops on the seabed.

Suckwells

Suckwells are the common name for relatively shallow absorption wells in karst limestone and are used, for example in Barbados, Jamaica and Antigua. Depths vary from 5m-15m and wells are dug to a depth that reaches a relatively large solution cavity or fissure in the limestone, allowing rapid infiltration of the wastewater into the groundwater. Due to the rapid infiltration, it is recommended that only high quality effluent be discharged to suckwells.

Table 11: Land Disposal Methods

Feature	Slow Rate	Rapid Infiltration	Overland Flow
Application Technique	Sprinkler or Surface	Usually Surface	Sprinkler or Surface
Annual Loading Rate, m	0.5 – 6	6 – 125	3 – 20
Field Area Required, ha	23 – 280	3 – 23	6.5 – 44
Typical Weekly Loading Rate, cm	1.3 – 10	10 – 240	6 – 40
Minimum preapplication treatment recommended in the US	Primary Sedimentation	Primary Sedimentation	Grit Removal and comminution
How the Wastewater is removed from the Soil	Evapotranspiration and Percolation	Mainly Percolation	Surface Runoff and Evapotranspiration with some Percolation
Treatment Effectiveness	Excellent	Very Good	Fair
Need for Vegetation	Required	Optional	Required
Suitable Soil Types	Loamy, Medium Textured. Sandy with certain crops	Sandy/Loamy Soils	Fine Textured Soil

Table 12: Comparison of Typical Effluent Qualities from Land Disposal Methods

Treatment System	Biological Oxygen Demand (mg/L)	Suspended Solids (mg/L)	Total Nitrogen (mg/L)	Phosphorus (mg/L)
Rapid Infiltration	<5	<5	10	2
Overland Flow	5	10 – 20	30	4
Slow Rate	1	1	5	<1

Source: Opus Environmental Training Centre, Principle and Trends in Wastewater Treatment Manual (1998)

4.7 Industrial Wastewater Treatment

The Caribbean is not a heavily industrialised region, except perhaps for Trinidad & Tobago. However, there are some typical industrial wastewaters that require treatment prior to disposal. Examples of industrial wastewaters within the region include:

- Rum refinery and beer distillery waste
- Petroleum hydrocarbon contaminated wastewaters from, for example, oil refineries, oil terminals and electricity generating plants.
- Agro-processing wastes (e.g. the nutmeg industry in Grenada)
- Slaughterhouse wastes (animal/fish offal and blood)
- Heavy metal contaminated wastewaters from electroplating industries
- Hot, high saline water from cooling towers
- High Saline water from Desalination Plants

Treatment technologies need to be specifically tailored to the targeted industrial effluent and the treatment standard desired. Typical technologies used to treat industrial wastewaters include:

- Settling tanks or clarifiers (with or without the use of coagulants, flocculating, or precipitating agents)
- Filtration units, including sand filters and membranes
- Dissolved Air Flotation (DAF) units
- American Petroleum Industry (API) separators
- Lagoons (aerobic, facultative and anaerobic)
- Activated carbon Filters
- Anaerobic digestors

Pretreatment of industrial wastewaters prior to discharge to a domestic wastewater treatment system is regulated by the LBS protocol referred to in section 4.6. The LBS Protocol stipulates the following:

"Each Contracting Party shall endeavour, in keeping with its economic capabilities, to develop and implement industrial pre-treatment programmes to ensure that industrial discharges into new and existing domestic wastewater treatment systems:

- do not interfere with, damage or otherwise prevent domestic wastewater collection and treatment systems from meeting the effluent limitations specified in this Annex;
- do not endanger operations of, or populations in proximity to, collection and treatment systems through exposure to toxic and hazardous substances;
- do not contaminate sludges or other reusable products from wastewater treatment; and
- do not contain toxic pollutants in amounts toxic to human health and/or aquatic life.

Each Contracting Party shall endeavour to ensure that industrial pre-treatment programmes include spill containment and contingency plans.

Each Contracting Party, within the scope of its capabilities, shall promote appropriate industrial wastewater management, such as the use of recirculation and closed loop systems, to eliminate or minimise wastewater discharges to domestic wastewater systems."

4.8 Zero Discharge

Zero discharge is a technical term describing one hundred percent (100%) wastewater discharge. This translates to treatment and total reuse of the water rather than disposal to surface waters or sewers. Increasingly, there has been a growing recognition that the world cannot continue to deplete its resources at the current rate; to do so will result in the destruction of our environment. The world is not an infinite source of raw materials or infinite receptacle for waste.

Human activity has always had an impact on the environment from prehistoric times when hunting was an important survival skill, to the invention of agriculture and domestication of animals all of which affected the fauna, flora and forest cover. However, the industrial revolution was the turning point in the relationship between Man and the environment. The industrial revolution brought with it a dramatic growth of the productive forces and a parallel growth in consumption. In addition, the human population on earth is now roughly six billion people; eighty percent of the global population lives in developing countries. The resulting consumptive society made intensive use of natural resources and produced huge quantities of waste. As human activities grew so did the resulting environmental pollution and the gravity of environmental disasters.

The Caribbean region is not immune to these global trends and must adopt a sustainable approach to the development of its island states many of which are dependent on the natural resource base for economic development. Zero discharge is on approach to wastewater treatment, which embraces the sustainable development concept.

Zero discharge of wastewater could result in two major benefits: dramatically reduced pollution and an indefinitely expanded resource base through recycling. The following section shows examples of zero discharge in wastewater treatment options.

Composting Toilets

Regarding human waste the closest technology to achieve a "zero" discharge into the environment is the composting toilet. Composting toilets, as described earlier are an on-site sewage management technology that can offer significant protection for water quality and quantity since the toilets provide dry, biological treatment of human excrement and do not generate quantities of contaminated water that must be discharged into the environment.

Membrane Filtration

The increased environmental awareness and stringent legislation have forced the paper and cellulose industry to reduce their water consumption. Normally the wastewater from a paper plant is biologically treated. However the quality of the effluent may be good enough for disposal but it is not high enough for reuse as process water. One method to clean the water is to use membrane filtration. The types of membrane filters that can be used are; micro filtration (MF), ultra filtration (UF) and nano filtration (UF). There are also experiences with a new type of membrane called the ceramic membrane. This membrane is used because it is easier to clean by the backflushing principle, compared to a carbon filter.

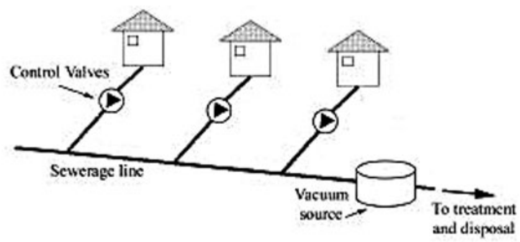
Ozonation

In the poultry industry carcasses are cooled in cold water, before being processed further. This cooling water gets turbid and contaminated with microorganisms like E. Coli and Salmonella. For reuse, the cooling water has to be transparent and free from bacteria. This can be achieved by means of filtration and ozone treatment. Ozone is the second most powerful sterilant in the world and its function is to destroy bacteria, viruses and odours.

4.9 Other Wastewater ESTs

The following ESTs have been included in the Directory for completeness. These are seldom, if ever, used in the Caribbean, but should not be discounted for future consideration.

Collection and Transfer Systems:
Vacuum Sewerage



Source: T. Loetscher (1998)

Technology Description:

Vacuum sewerage systems use a central vacuum source to convey sewage from individual households to a central collection station. A valve separates the atmospheric pressure in the home service line from the vacuum in the collection mains. The valve periodically opens based on volume stored to allow wastewater and air to flow into the vacuum collection mains. The wastewater is propelled in the collection main from the differential pressure of a vacuum in front and atmospheric pressure in the back. Eventually the air pressure in the collection main equalises and all flow ceases until the next valve from a service line is opened. Through this process, wastewater is conveyed to a central collection tank. From there, it can be conveyed by gravity or by a pump station through a force main to its final destination. Vacuum sewers are typically used in low population density areas where the terrain will not permit gravity flow to a central location or treatment facility.

Extent of Use:

Not used in the Caribbean.

Operation and Maintenance:

- High degree of operation and maintenance is required
- Skilled personnel required

Advantages:

- Lower capital cost than conventional sewerage
- No worries to household users
- Provides good service to households
- Promotes good hygienic practices.

Disadvantages /constraints:

- Smaller diameter pipes may result in a higher risk of blockages and thus increased maintenance.
- High technology requiring skilled engineers, contractors and operators.
- Ample and reliable piped water supply required
- Possible odour problem from venting

Relative Cost:

- High but less than conventional sewerage

Cultural Acceptability:

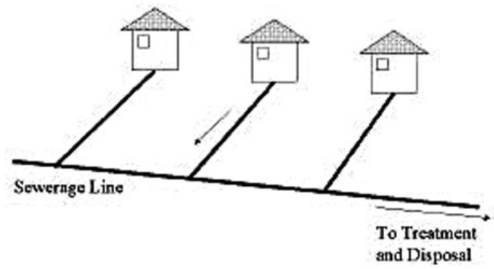
- Is generally accepted within the Caribbean Region

Suitability:

- In urban areas that have the resources to implement, operate and maintain systems plus provide adequate treatment to avoid pollution at the discharge end.

Collection and Transfer Systems:

Simplified Sewerage (smaller diameter pipes than conventional sewerage)



Source: T. Loetscher (1998)

Technology Description:

Similar to conventional sewerage systems, household sewage is collected by an underground pipe system to treatment facilities or directly into receiving waters or land application. However design criteria for construction are much less conservative allowing for minimum hydraulic requirements. This results in cost saving from:

- Smaller pipe diameters
- Flatter pipe gradients
- Shallow pipe depths
- Fewer access chambers
- Smaller pumps

Note that this type of collection system better suits the "settled sewerage" system where most solids are removed using an onsite septic tank before entering the small diameter reticulation system.

Extent of Use:

Not used often within the Caribbean Region.

Operation and Maintenance:

- High degree of operation and maintenance required especially if pumping is required
- Skilled personnel required
- Higher blockage risk than conventional sewerage

Advantages:

- Lower capital cost than conventional sewerage
- No worries to household users
- Provides good service to households
- Promotes good hygiene practices.

Disadvantages /constraints:

- Smaller diameter pipes may result in a higher risk of blockages and thus increased maintenance.
- High technology requiring skilled engineers, contractors and operators.
- Ample and reliable piped water supply required
- Adequate treatment and/or disposal required for a large point source discharge.

Relative Cost:

- High but less than conventional sewerage

Cultural Acceptability:

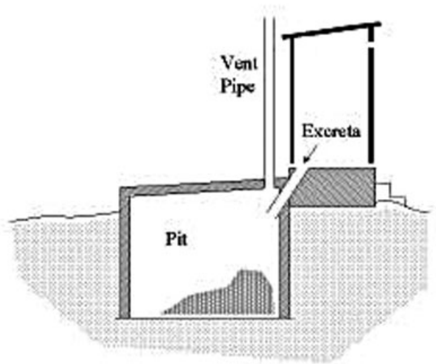
- Is generally accepted within the Caribbean Region

Suitability:

- In urban areas that have the resources to implement, operate and maintain systems plus provide adequate treatment to avoid pollution at the discharge end.

On-Site Wastewater Treatment

Reed Odourless Earth Closet



Source: T. Loetscher (1998)

Technology Description:

The Reed odourless earth closet (ROEC) is designed for the on-site disposal of human excreta. From the concrete squatting plate or riser, an inclined chute leads to the completely off-set pit. Ventilation is similar to the VIP latrine. Its design life is between 15 - 30 years. If less than 10 years, a double vault composting (DVC) latrine should be considered instead.

Because it is off-set, the pit can be built larger than that of the conventional pit latrine. In loose soil, the entire pit should be lined in order to prevent collapse.

ROECs do not need water for flushing and are simple to construct. If constructed properly, they provide good health benefits.

All types of anal cleansing materials may be used. Since the chute is inclined, excreta cannot be seen through the hole in the squatting plate.

Since ROECs involve soil absorption, there is a danger of groundwater contamination. A ROEC can be upgraded to a latrine with vault or a pour-flush latrine.

Extent of Use:

No known use

Operation and Maintenance:

- Easy to operate and maintain
- Chute must be kept clear of blockages

Advantages:

- One unit can serve one or several households.
- Does not require water
- The potential for self help is high.
- Good ventilation largely prevents odours and insect nuisance.

Disadvantages /constraints:

- This facility cannot receive greywater.
- Fouling of the chute is often a problem
- Danger of groundwater contamination

Relative Cost:

- Moderate

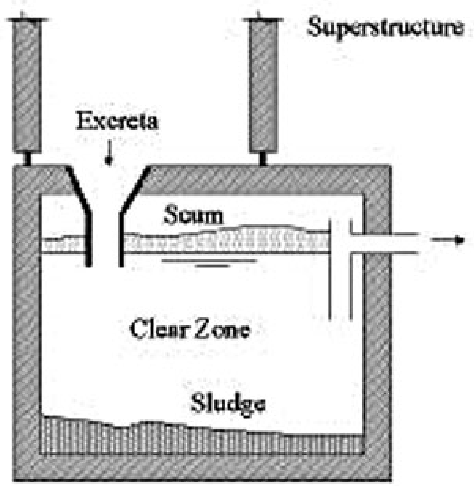
Cultural Acceptability:

- Culturally accepted

Suitability:

- Suitable in water short areas, however contaminated groundwater may be an issue.

On-Site Wastewater Treatment
Aquaprivy



Note: Effluent should be disposed of through drainage field or seepage pit
Source: T. Loetscher (1998)

Technology Description:
The aquaprivy is designed for the on-site collection and treatment of domestic sewage. Excreta fall through a submerged chute into a watertight tank, which is located underground. The liquid in the tank provides a water seal to reduce odours and insect nuisance.

There are two main treatment effects:

1) Contaminants are removed from the sewage by either the settling of heavy particles or by flotation of materials less dense than water (e.g. oils and fats). The sludge layer at the bottom of the tank is a result of the settling process. The scum layer is formed through the flotation process.

2) Subsequently, organic matter in the sludge as well as the scum layer is digested by bacteria. As a result, gas is produced which emerges through a ventilation opening in the tank. The digestion process is important because it prevents the excessive accumulation of sludge.

Greywater has to be collected and discharged separately.

Extent of Use:
No known use

Operation and Maintenance:
- Accumulated sludge needs to be pumped out every one to three years, which requires special equipment such as vacuum trucks.
- For flushing and in order to maintain the water seal, approximately five litres of water is required per person per day.
- Besides cleaning the chute, there is no other maintenance required.

Advantages:
- There is some potential for self help
- Aquaprivies can be upgraded to septic tanks and settled sewerage.

Disadvantages /constraints:
- If not well constructed, tanks may not be watertight As a consequence, it is difficult to maintain the liquid level and thus the water seal, with resulting bad odours and the risk of groundwater contamination.

Relative Cost:
- High

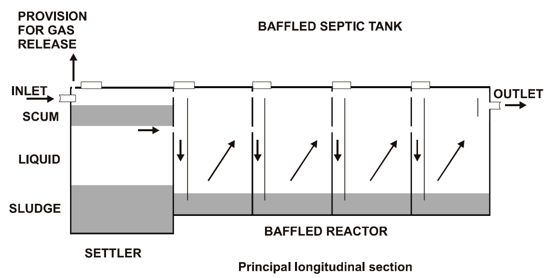
Cultural Acceptability:
- Culturally accepted

Suitability:
- May be suitable if space is a problem, otherwise septic tanks are a better option.

Secondary Process

Reactors

Baffled Septic Tanks



Note: Both greywater and blackwater can be flushed through the system. Since they only accept liquid waste must be connected to a flush toilet.

Source: Flow Principle of baffled septic tank after Ludwig, S. 1998

Technology Description:

This process is suitable for all kinds of wastewater including domestic. The baffled septic tank consists of an initial settler compartment and a second section of a series of baffled reactors. Sludge settles at the bottom and the active sludge that is washed out of one chamber becomes trapped in the next. The reason for the tanks in series is to assist in the digestion of difficult degradable substances especially towards the end of the process. For the purpose of quicker digestion, influent, upon entering the process, is mixed with active sludge present in the reactor. Wastewater flows from bottom to top causing sludge particles to settle on the upflow of the liquid wastewater allowing contact between sludge already present with incoming flow. A settler can be used for treatment after effluent has left the tank. Hydraulic and organic shock loads have little effect on treatment efficiency.

The treatment efficiency achievable is 70-95% BOD removal, 65-95% COD removal and the resulting effluent quality is moderate

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Sludge removal is important and must be done regularly
- Flow regulation is also important, as up-flow velocity should not exceed 2m/h.
- Moderate operation and maintenance requirements

Advantages:

- No electrical requirements
- Construction material locally available
- Low land space required

Disadvantages /constraints:

- Needs skilled contractors for construction

Relative Cost:

- Low

Cultural Acceptability:

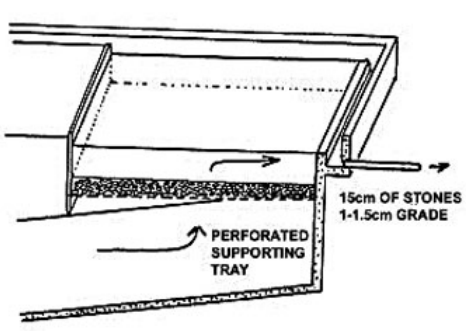
- Is generally accepted within the Caribbean Region

Suitability:

- Not suitable where water supply scarce or unreliable.

Tertiary Process

Banks' Clarifiers



Source: After Mann, H.T., Williamson, D., 1982

Technology Description:

Banks' Clarifiers are a compact tertiary treatment process. It is essentially an upward flow filter containing a bed of gravel that is supported on a perforated base. The accumulation of solids occurs within and on the upper surface of the gravel layer. The bed should be cleaned when the upper surface is covered or when suspended solids concentration in the final effluent rises.

Typical effluent treatment quality performed on secondary treated effluent is 30% BOD removal, 50% Suspended solids removal and 25% E. Coli removal

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Requires removal of solids, which accumulate on the upper surface of the gravel bed layer.

Advantages:

- Low operation and maintenance
- Construction material available locally
- No electrical requirement
- High Effluent Quality

Disadvantages /constraints:

- High land space required
- High volume of water required

Relative Cost:

- Moderate

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

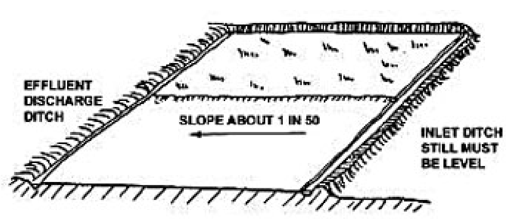
Suitability:

- Since only receive liquid waste not suitable where water scarce or unreliable.

Tertiary Process

Plots

Grass Plots



Source: After Mann, H.T., Williamson, D., 1982

Technology Description:

Grass plots are simple to construct with high rates of removal. Plots should be even and sloped towards collection areas. Basically effluent passes through the mesh of the grass blades that then filter out solids in a well-aerated environment. The possibility of contamination of groundwater should be considered, as some effluent will percolate into porous ground. Coarse natural grass is satisfactory. Surplus grass needs to be removed and cuttings should be disposed of properly as there could be danger of further pollution as they decompose.

Typical treatment quality performed on secondary treated effluent is 50% BOD removal, 70% Suspended solids removal, 90% E. Coli removal.

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Requires removal of solids but only when they are seen to physically prevent the flow
- Surplus grass needs to be removed

Advantages:

- Simple to construct.
- Low operation and maintenance
- Construction material available locally
- No electrical requirement
- High Effluent Quality

Disadvantages /constraints:

- High land space required
- Possible water contamination from runoff
- High volumes of water required

Relative Cost:

- Moderate

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

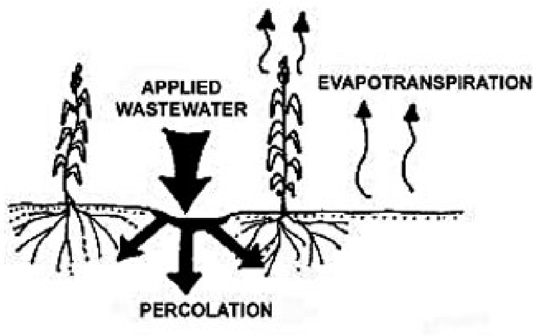
Suitability:

- Since only receive liquid waste not suitable where water scarce or unreliable.

Land Disposal

Land Treatment

Slow Rate Process



Technology Description:

The processes of land treatment are selected mainly on the basis of soil permeability of the treatment site. Prior to land treatment there needs to be preliminary treatment through either screening, grit removal or primary sedimentation to reduce soil clogging and to prevent nuisance conditions from occurring. Slow rate process requires a soil permeability of 5 to 50mm/hr and a depth of a minimum of 1m to groundwater. It should be in a site with a clay loam to sandy loam soil type with a slope of less than 15% for cultivated land and less than 40% for forested land. Disposal of effluent can be through evapotranspiration and percolation. There is a need for vegetation with Slow Rate Process.

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Requires regular operation and maintenance input.

Advantages:

- Low operation and maintenance
- No electrical requirement
- Construction material locally available

Disadvantages /constraints:

- High land space requirement

Relative Cost:

- Moderate (land and irrigation costs)

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

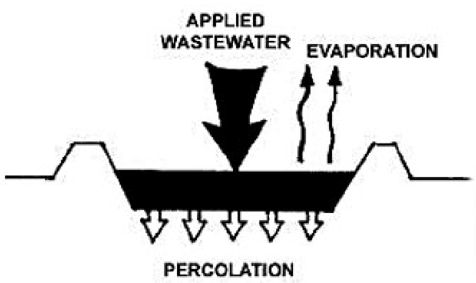
Suitability:

- Since they only receive liquid waste they are not suitable where water supply scarce or unreliable
- Requires high volumes of water for transportation to treatment site.

Land Disposal

Land Treatment

Overland Flow Process



Technology Description:

Overland is also a land treatment process and requires preliminary treatment of grit, screening etc. In the overland flow process the soil permeability should be less than 5mm/hr. The depth to groundwater is not critical and the soil type should be either clay, silts and soils with impermeable barriers, the slope of the area being between 1-8%. Surface runoff and evaporation with some percolation can dispose of the effluent. There is a need for vegetation in the overland flow process.

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Requires occasional operation and maintenance input.

Advantages:

- Low operation and maintenance
- No electrical requirement
- Construction material locally available

Disadvantages /constraints:

- High land space required

Relative Cost:

- Moderate

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

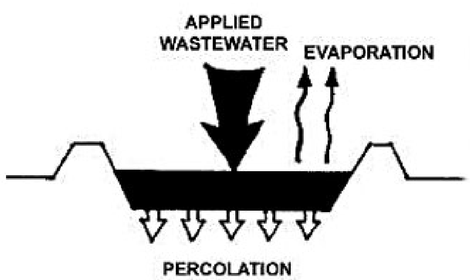
Suitability:

- N/A

Land Disposal

Land Treatment

Rapid Infiltration Treatment Process



Technology Description:

The Rapid Infiltration Land Treatment process also needs to be preceded by preliminary treatment in order to reduce soil clogging and prevent nuisance conditions from occurring. This treatment process can only be used in soils having a permeability of greater than 50mm/hr. The depth to groundwater should be a minimum of 3m in sandy or sandy loam soil types. The disposal of effluent is done mainly through percolation.

Typical treatment quality achieved is 86-100% BOD removal, 100% suspended solids removal (dependent on several factors e.g. rest cycles and/or cleaning), 10-93% nitrogen removal, 29-99% phosphorus removal

Extent of Use:

Limited use in the Caribbean Region

Operation and Maintenance:

- Requires regular operation and maintenance input.

Advantages:

- Low operation and maintenance
- No electrical requirement
- Construction material locally available.
- High effluent quality

Disadvantages /constraints:

- High land requirement

Relative Cost:

- Moderate

Cultural Acceptability:

- Is generally accepted within the Caribbean Region

Suitability:

- Since only receive liquid waste not suitable where water scarce or unreliable.
- Requires high volumes of water for transportation to treatment site

5.0 Information Sources for the Caribbean

CAREC
Caribbean Epidemiology Center
16-18 Jamaica Boulevard
Federation Park
Port-of-Spain, Trinidad
P. O. Box 164
Port-of-Spain, Trinidad
email: email@carec.ops-oms.org
Tels: 868-622-4261, 622-4262, 622-3168, 622-3277
Fax: 868-622-2792

Caribbean Conservation Association (CCA)
The Garrison,
St. Michael, Barbados
Tel: (246) 426-5373
Fax: (246) 429-8483
www.ccanet.net

Caribbean Development Bank (CDB)
P.O. Box 408
Wildey, St. Michael
Barbados
Tel. No. (246)431-1600
Fax No. (246)426-7269
Email: info@caribank.org
www.caribank.org

Caribbean Environmental Health Institute (CEHI)
P.O. Box 1111
Morne Fortune, Castries, Saint Lucia
Tel: (758) 452-2501
Fax: (758) 453-2721
Email: cehi@candw.lc
www.cehi.org.lc

Caribbean Natural Resources Institute (CANARI)
Fernandes Industrial Centre
Administration Building
Eastern Main Road, Laventille, Trinidad and Tobago
Tel: 868 626 6062
Fax: 868 626 1788
E-mail:info@canari.org
www.canari.org

Caribbean Water & Wastewater Association (CWWA)
Registered Office:
Republic of Trinidad & Tobago
Tel/Fax: 868-645-7849
Tel:868-662-2302 Ext. 3747
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